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UNITED STATES DISTRICT COURT
FOR THE NORTHERN DISTRICT OF CALIFORNIA

FULLVIEW, INC., a Delaware corporation,

Plaintiff,

vs.

POLYCOM, INC., a California corporation,

Defendant.

§ Case No. 3:18-cv-00510 EMC

§

§ **AMENDED COMPLAINT**

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§ Filing Date of Original Complaint:

§

January 23, 2018

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§ **JURY TRIAL DEMANDED**

1 Plaintiff FullView, Inc. (“FullView” or “Plaintiff”) hereby files its Amended Complaint
2 against Defendant Polycom, Inc. (“Polycom” or “Defendant”) for patent infringement. For its
3 complaint, Plaintiff alleges, on personal knowledge as to its own acts and on information and
4 belief as to all other matters, as follows:

5
6 **PARTIES**

7 1. Plaintiff FullView is a corporation organized under the laws of the State of
8 Delaware and has its principal place of business in Holmdel, New Jersey. FullView is and at all
9 pertinent times was the assignee and owner of the patents at issue in this case.

10 2. Defendant Polycom is incorporated under the laws of the State of California and
11 has its principal place of business in San Jose, California.

12
13 **JURISDICTION AND VENUE**

14 3. This Complaint asserts a cause of action for patent infringement under the Patent
15 Act, 35 U.S.C. § 271.

16 4. This Court has subject matter jurisdiction over this matter by virtue of
17 28 U.S.C. § 1338(a).

18 5. The venue of this Court is proper by virtue of 28 U.S.C. § 1391(b) and (c) and
19 28 U.S.C. § 1400(b) in that (i) Polycom may be found in this district, (ii) Polycom committed
20 acts of infringement in this district, (iii) a substantial portion of the events or omissions giving
21 rise to this complaint occurred in this district and (iv) a substantial portion of the property that is
22 the subject of this complaint is situated in this district.

23 6. This Court has personal jurisdiction over Polycom because Polycom provides
24 infringing products and services in the Northern District of California.
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BACKGROUND

The FullView Patents

7. Plaintiff owns several patents, all deriving from the inventions of Dr. Vishvjit Singh (Vic) Nalwa, who has been President of FullView since founding it with Bell Labs in 2000.

8. FullView is a Prime Contractor for the U.S. Navy that provides the Navy with 360° panoramic cameras for its most advanced aircraft carriers, such as the USS Gerald R. Ford.

9. Dr. Nalwa received a Ph.D. in Electrical Engineering from Stanford University in 1987, after which he was a Principal Investigator at Bell Labs Research until he co-founded FullView. In 1989, he was also on the faculty of Princeton University. From 1994 to 1998, he was an Associate Editor of the *IEEE Transactions on Pattern Analysis and Machine Intelligence*, the preeminent journal in his field. He holds 14 U.S. patents on his omni-directional camera inventions for which in 2004 he was elected a Fellow of the IEEE — an honor awarded to no more than 0.1% of IEEE’s total voting membership in a year. He has given invited technical talks worldwide, including at MIT, Stanford, CMU, UC Berkeley, Harvard, Princeton, Yale, Google, Technion, UBC, TU Delft, HKU, IIT Delhi and INRIA. He is the author of *A Guided Tour of Computer Vision*, Addison-Wesley, 1993, a course text that has also been used for Ph.D. qualifying exams in Artificial Intelligence and Computer Science, *e.g.*, by Stanford University.

10. U.S. Patent No. 6,700,711 (“the ’711 Patent”) entitled “Panoramic viewing system with a composite field of view” was issued on March 2, 2004 and expired on November 30, 2015. A true and correct copy of the ’711 Patent is attached as Exhibit “A” and is incorporated herein by reference. Plaintiff is the legal and rightful owner of the ’711 Patent.

11. U.S. Patent 6,128,143 (“the ’143 Patent”) entitled “Panoramic viewing system with support stand” was issued on October 3, 2000 and expired on August 28, 2018. A true and correct copy of the ’143 Patent is attached as Exhibit “B” and is incorporated herein by reference. Plaintiff is the legal and rightful owner of the ’143 Patent.

1 12. The '711 Patent contains thirty-nine (39) patent claims covering a unique and
2 novel method, product of method (*i.e., composite image*), and system and apparatus for an omni-
3 directional or panoramic viewer. The '711 invention describes several cameras looking in
4 different directions from *offset viewpoints*, off mirrors, allowing a user to seamlessly look in any
5 direction at a portion of or a complete 360° composite image. This invention can enhance virtual
6 meetings by allowing an unlimited number of remote users to simultaneously simulate sitting in
7 a physical meeting room (*perhaps in a different country*) in which each user is free look in any
8 direction.

9 13. The '143 Patent contains eighteen (18) patent claims covering a unique and novel
10 system and apparatus for a compact and non-intrusive omni-directional or panoramic viewer in
11 which several cameras look off a mirrored pyramid, this pyramid and these cameras secured to a
12 support member that intersects an inner volume of the pyramid. This invention builds on the
13 invention of the '711 Patent by providing it with ease and preciseness in assembling and
14 calibrating its camera-mirror arrangement — thereby reducing manufacturing costs.

15 16 **FullView License to Polycom**

17
18 14. Effective April 1, 2011, Polycom licensed from FullView the '711 and '143
19 Patents among others under an Intellectual Property Agreement (“IPA”) between the parties that
20 allowed Polycom to manufacture and sell infringing low-resolution products worldwide,
21 including its CX5000 product (“CX5000”) that provides panoramic 360° video for
22 videoconferencing applications.

23 15. Polycom’s CX5000 product was previously manufactured and marketed as the
24 RoundTable product (“RoundTable”) by Microsoft Corporation (“Microsoft”), also under license
25 from FullView. As the two products are evidently identical but for their labeling, Polycom often
26 referred to “CX5000” as “RoundTable” in its communications with FullView.

1 Products worldwide — these products being manufactured and/or imported by Polycom at dates
2 unknown to Plaintiff.

3 20. On January 4, 2017, the Patent and Trial Board (“PTAB”) of the USPTO affirmed
4 the validity of *all* 39 claims of the ’711 Patent in the IPX — but not before it had first disallowed
5 *every* claim in its Original Decision on September 29, 2014, this decision swayed by a persistent
6 technical misrepresentation by Polycom that Polycom ultimately abandoned when it proffered an
7 expert declaration to counter an expert declaration by FullView.

8 21. The Original PTAB Decision — by asserting a “new” issue of patentability that
9 combined the two IPX references as disallowed by the Director — allowed FullView to reopen
10 prosecution and establish that “Uehira” when properly read does not render any claim of the ’711
11 Patent obvious or anticipated.

12 22. Polycom appealed the final PTAB IPX decision to the U.S. Court of Appeals for
13 the Federal Circuit (“CAFC”), which affirmed the decision on April 29, 2019.
14

15 **Inter Partes Review of the ’143 Patent**

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17 23. On January 31, 2019, Polycom challenged claims 1–3 and 10–12 of FullView’s
18 ’143 Patent in an *Inter Partes* Review (“IPR”) Petition.

19 24. This Petition included another technical misrepresentation, though this time
20 through an expert declaration that FullView countered with an expert declaration by Dr. Nalwa.
21 The PTAB denied this Petition — and then denied Polycom’s Rehearing Request on this Petition
22 on September 10, 2019.

23 25. Polycom thus exhausted *every* possible challenge at the USPTO, and then CAFC,
24 to the validity of every claim of the ’711 Patent and to claims 1–3 and 10–12 of the ’143 Patent.
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Polycom's Infringing Goods And Services

26. As alleged above, the '711 Patent issued on March 2, 2004 and the '143 Patent issued on October 3, 2000. On information and belief, Polycom was well aware of these and other FullView patents well before Polycom announced on March 30, 2009 that it would be selling worldwide the Microsoft Roundtable product renamed as the Polycom CX5000.

27. On June 15, 2009, Dr. Nalwa emailed Mr. Robert C. Hagerty, Chairman and CEO of Polycom at the time, that Microsoft's license to FullView's patents for its RoundTable product excluded any "right to sublicense" FullView's patents.

28. On July 16, 2009, Dr. Nalwa described FullView's patents to Polycom in a presentation he gave at its San Jose offices under a non-disclosure agreement ("NDA") retroactive to this date. At this meeting, he *specifically* pointed out to those present, including to Mr. Jeff Rodman, co-founder of Polycom, that FullView's patent license to Microsoft was "non-sublicensable." He subsequently informed Mr. Keith Rutherford of Polycom's outside counsel law firm of this, both by email and in a video conference, to both of which Mr. Rodman was a party.

29. Nevertheless, on information and belief, since a time known to Polycom but not to FullView, Polycom has *made and sold worldwide*, without a license from FullView, allegedly infringing products that provide panoramic 360° video for videoconferencing applications:

- (i) Polycom apparently *made and sold* CX5000 (or RoundTable) products before it entered into an IPA with FullView effective April 1, 2011, but it concealed this from FullView.
- (ii) Polycom continued to *sell* previously *made* CX5000 products after the IPA's term, but it did not disclose this to FullView, as the IPA required, until the aforementioned arbitration.
- (iii) Polycom apparently *made* CX5000 Successor Products — such as the CX5000 HD, CX5100, CX5500, CX8000 360° and RealPresence Centro products — since at least 2011, and then *sold* them starting no later than around January 2012 to beyond the expiration of the asserted patents.

Infringement of the '711 Patent

30. The invention of the '711 Patent is captured in its “process” or method claims, such as 1, 2, 5, 6 and 9 below; in its “machine” or apparatus claims, such as 16, 19 and 22; and in its “manufacture” or product-of-method claims, such as 25, 26, 29, 30 and 33:

1. A method of producing a composite image with a plurality of sensors each having an individual field of view, comprising the steps of:

for at least one of the plurality of sensors, redirecting at least a portion of its individual field of view with a reflective area; and

merging images corresponding to the individual fields of view to produce the composite image having a corresponding field of view, wherein each one of at least two fields of view corresponding to images that are merged has a portion, where the images are merged, that has viewing directions that are substantially similar to the viewing directions of the other portion, and wherein the viewing directions within each one of such two portions appear to originate substantially from a point that is offset from the point for the other one of such two portions.

2. The method of claim 1, wherein the field of view corresponding to the composite image has at least one blind region that encompasses at least a portion of an edge of a reflective area and that lies between the two portions of the two individual fields of view.

5. The method of claim 1, wherein images corresponding to the individual fields of view are merged electronically by merging data representative of the fields of view to produce data representative of the composite image and data representative of the composite image is stored by electronic means.

6. The method of claim 5, further comprising displaying the composite image selectively using a control means to select a portion of the composite image to be displayed.

9. The method of claim 5, further comprising displaying at least a portion of the composite image remotely after transmitting this portion over a communication network.

31. Although all 39 claims of the '711 Patent are infringed, to simplify these proceedings, FullView asserts only the following claims: 1, 2, 4, 5, 9, 11, 13, 15, 16, 18, 19, 21, 22, 24, 25, 26, 28, 29, 33, 35, 37 and 39.

1 32. On information and belief, the CX5000 and CX5000 Successor Products
2 implement the method, apparatus and product-of-method of the '711 Patent in a manner identical
3 to that of the Microsoft RoundTable product. This was recently conceded by Polycom in a filing
4 in this Court wherein it stated: "Polycom now uses" "the very solution Microsoft independently
5 developed," conceding that only a single "solution" was developed by Microsoft and then used
6 by Polycom. Therefore, to establish that *any* accused product infringes *any* claim, it is sufficient
7 to establish that the RoundTable product infringes that claim.

8 33. The RoundTable product provides panoramic 360° video for videoconferencing
9 applications using the camera-mirror arrangement of Figure 2 of the '711 Patent, but with five
10 cameras ("sensors") instead of four. A five-sided mirrored pyramid "redirecting at least a portion
11 of" each camera's "individual field of view with a reflective area" (mirror) is followed by
12 "merging images corresponding to the individual fields of view to produce the composite image"
13 (claim 1). This "composite image" — created "electronically by merging data representative of
14 the fields of view to produce data representative of the composite image" that "is stored by
15 electronic means" (claim 5) — excludes views of the world within five "blind regions," each of
16 which "encompasses at least a portion of an edge of a reflective area" (claim 2). The active
17 speaker's voice is the "control means to select a portion of the composite image to be displayed"
18 (claim 6) "remotely after transmitting this portion over a communication network" (claim 9).

19 34. The only claim limitations in any '711 Patent claim not clearly demonstrated
20 expressly in the specification of the RoundTable product are these, both these limitations
21 infringed by the RoundTable's implementation of the geometry of Figure 14 of the '711 Patent:
22

- 23 (i) Portions of the "two fields of view" "where the images are merged" have "viewing
24 directions that are substantially similar" but "appear to originate substantially" from
25 "offset" points (claim 1) — each such claimed point, termed a "viewpoint" in the IPX,
26 equivalent to a "pinhole" in a "pinhole camera."
- 27 (ii) A "blind region that encompasses at least a portion of an edge of a reflective area" "lies
28 between the two" foregoing "portions of the two individual fields of view" (claim 2).

1 Unsurprisingly then, these claim limitations were the focus of the parties' dispute in the IPX.

2 35. To see that the RoundTable product implements the geometry of Figure 14 of the
3 '711 Patent, first consider Exhibit "C", which shows the RoundTable camera head, both
4 assembled and disassembled. In the upper photograph, there is clearly an "offset" between the
5 apparent apertures of adjoining cameras lenses as seen in the mirrors — that is, the lens apertures
6 appear to be side by side after reflection, rather than coincident — which establishes the "offset"
7 claimed in claim 1.

8 36. Next, consider Exhibit "D", which shows two sets of video stills from the
9 RoundTable product — captured by Dr. Nalwa at Bell Labs, Murray Hill, NJ on September 17,
10 2008 and on April 15, 2009 — each video still "displaying the composite image selectively using
11 a control means to select a portion of the composite image to be displayed" (claim 6). In each
12 displayed "portion of the composite image" in each set of images, a yardstick placed across the
13 same mirror edge has missing from it roughly an eighth of an inch along where the annotating
14 arrow points, *no matter the distance of the yardstick* from that mirror edge. This is verified by
15 counting the number of eighth-inch intervals in an inch of the yardstick across the "blind region."
16 Nothing in either scene within this roughly eighth of an inch that embraces the mirror edge can
17 be seen in the composite image, this composite image otherwise geometrically "substantially"
18 continuous. These observations establish that the RoundTable implements every aspect of the
19 geometry of Figure 14 of the '711 Patent — as readily seen by considering "pinhole cameras":
20

- 21 (i) a "blind region" of roughly constant width within "the field of view corresponding to the
22 composite image," this "blind region" "encompassing" a mirror edge as in claim 2;
- 23 (ii) "viewing directions that are substantially similar" in portions of the "two fields of view"
24 "where the images are merged" as in claim 1 — as else objects across the "blind region"
25 would not appear geometrically "substantially" continuous in the composite image *no*
26 *matter what the object and what its location* in the scene; and
- 27 (iii) "offset" viewpoints of "such two portions" of "two fields of view" as in claim 1 — as
28 also seen from Exhibit "C" — as else the "blind region" would expand with distance.

1 37. This showing that the RoundTable implements *every* aspect of the geometry of
2 Figure 14 of the '711 Patent is unaffected by whether the RoundTable also successfully matches
3 image color and brightness across the “blind region” — as it does in one set of images in Exhibit
4 “C”, but not in the other set. “Uehira” and a FullView expert declaration in the IPX attest to
5 image color and brightness matching being independent of the technique used to “merge” the
6 images geometrically. Thus, *every* '711 claim is infringed by *every* accused product.

7 38. Whereas Polycom alleges in the Joint CMC Statement that the RoundTable, “the
8 very solution” “Polycom now uses,” was “independently developed” by Microsoft, it is no
9 coincidence that the RoundTable implements the geometry of Figure 14 of the '711 Patent:

- 10 (i) Dr. Nalwa had shared a Bell Labs Technical Memorandum describing his implementation
11 of Figure 14 of the '711 Patent — with eighth-inch-thick “blind regions” and image color
12 and brightness matching — with Dr. Richard Szeliski, a Microsoft researcher, in 1996.
- 13 (ii) In October 2002, Microsoft had unsuccessfully sought to borrow from FullView its
14 FC-1005 product that incorporated the '711 and '143 inventions and sold for \$70,000.
- 15 (iii) By then, the '143 Patent and several parents of the '711 Patent had issued while
16 Microsoft had been pursuing a mirrorless multi-camera design for years with which it
17 was unable to match the quality of composite images on FullView’s website —images
18 such as from FullView’s '711 prototype in Exhibit “E” that was used to webcast a widely
19 publicized live performance by Mr. David Bowie in New York City in May 1999.
- 20 (iv) In November 2003, FullView offered to license its patents to Microsoft, but to no avail.
21 Instead, in 2007, Microsoft launched its RoundTable product that closely resembled the
22 prototype of Exhibit “E” — with *five* cameras, “blind regions” and “offset” viewpoints.
- 23 (v) On April 29, 2008, FullView filed a complaint against Microsoft in this Court, alleging
24 that it had willfully infringed the '711 Patent. Microsoft settled this complaint within two
25 months to become a licensee of FullView effective June 25, 2008 under a Settlement and
26 License Agreement (“SLA”) between FullView and Microsoft.
27
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Infringement of the '143 Patent

39. The invention described and claimed in the '143 Patent generally relates to “machine” or apparatus claims such as claims 10, 11 and 12 below:

10. A panoramic viewing apparatus, comprising:

[a] plurality of image processing devices, each having an optical center and a field of view;

a pyramid shaped element having a plurality of reflective side facets facing in different directions, each of at least two of the plurality of reflective side facets redirecting a field of view of one of the plurality of image processing devices to create a plurality of virtual optical centers; and

a support member intersecting an inner volume of the pyramid shaped element, the pyramid shaped element being secured to the support member and the plurality of image processing devices being secured to the support member.

11. The panoramic viewing apparatus of claim 10, wherein the plurality of image processing devices are secured to a portion of the support member extending out from the pyramid shaped element.

12. The panoramic viewing apparatus of claim 10, wherein the support member is hollow.

40. The lower photograph in Exhibit “C” shows “image processing devices” (cameras) un-“secured” from a “hollow” “support member” “secured” to and “extending out” from an “inner volume” of a “pyramid shaped element” with “reflective side facts.” This establishes that each of claims 10–12, and therefore 1–3, is infringed by the RoundTable product.

41. Because, on information and belief, every accused product is structurally similar to the RoundTable product, every accused product also infringes each of claims 1–3 and 10–12.

42. Nevertheless, to simplify these proceedings, FullView asserts only claims 10–12.

Fraudulent Concealment, Willfulness and Exceptionality

43. As alleged above, Microsoft and Polycom announced that Polycom would sell the Microsoft Roundtable product renamed as the Polycom CX5000 on March 30, 2009, after which FullView allegedly informed Polycom *repeatedly* that FullView's license to Microsoft was "non-sublicensable." This prompted licensing discussions between the parties in 2009, under an NDA.

44. On February 28, 2011, Microsoft gave FullView a notice to terminate its license effective March 30, 2011. Upon FullView informing Polycom of this, the parties negotiated and entered into a patent license from FullView to Polycom as per their IPA effective April 1, 2011.

45. In negotiating this IPA, as in 2009, Polycom led FullView to believe that Polycom was embarking on new business activities that needed FullView's permission and that Polycom had not previously pursued any activity that might have required a FullView license.

46. On November 29, 2012, on information and belief, Mr. Rutherford of Polycom's outside counsel law firm affirmed this understanding of FullView by misrepresenting to it that sales of RoundTable (CX5000) by Polycom had been licensed thus: "All sales of RoundTable were licensed through Microsoft as of March 30, 2011 and were licensed through Polycom as of April 1, 2011." Mr. Rutherford copied this email to Mr. Sayed Darwish, General Counsel of Polycom, among others.

47. This misrepresentation has only recently been brought to light by Polycom's statement that "[i]n 2010 Polycom acquired manufacturing rights in the RoundTable product designed and launched by Microsoft in 2007."

48. As Polycom's "acquired manufacturing rights" could not include a (sub)license to FullView's patents, the only Polycom CX5000 (Roundtable) sales that could have *conceivably* been "licensed through Microsoft" — subject to discovery of all Microsoft–Polycom agreements — are of products made by Microsoft, and not of any product made by Polycom.

49. At some point after 2008, Polycom discontinued *making and selling* CX5000, and instead began *making and selling* CX5000 Successor Products that are not licensed by the IPA.

1 50. Concurrently, after the parties could not agree on royalties for CX5000 Successor
2 Products, Polycom initiated the aforementioned IPX proceedings before the USPTO, in which,
3 on information and belief, Polycom engaged in litigation abuse — designed to mislead and
4 confuse the Examiner and the PTAB and to delay the proceedings — by *inter alia* insisting that
5 prior art “Uehira” teaches “blind regions” and “offset viewpoints.”

6 51. Whereas Polycom conceded early in the IPX in response to FullView that
7 “Uehira” does not teach “blind regions,” it insisted for close to three years in the same IPX — in
8 the face of textbook-like tutorials by FullView at the USPTO — that “Uehira” teaches “offset
9 viewpoints,” recanting this misrepresentation *when and only when* PTAB’s Original Decision
10 disallowed all 39 claims of ’711 without explicitly relying on “Uehira” to teach “offset
11 viewpoints.”

12 52. In its IPR Rehearing Request too, Polycom admitted it had “slightly exaggerated”
13 the teachings of a prior art in its IPR Petition, but only after PTAB had already discovered this.

14 53. Polycom is a large, profitable and sophisticated multinational corporation in an
15 industry that demands highly specialized expertise from its participants. Polycom not only
16 employs full-time legal and intellectual property counsel, but also retains outside counsel for
17 both. On information and belief, it made the following decisions with full knowledge of their
18 potential legal and financial consequences:

- 19
- 20 (i) It made and sold CX5000 products prior to the IPA and then *fraudulently concealed* this.
 - 21 (ii) It failed to disclose all its CX5000 sales and other dispositions as required by the IPA.
 - 22 (iii) It gave a notice of termination of the IPA, but then disavowed this notice.
 - 23 (iv) In the ensuing arbitration, its disclosures were misleading and inconsistent.
 - 24 (v) It made and sold unlicensed CX5000 Successor Products worldwide starting at least 2012.
 - 25 (vi) It made *factual* misrepresentations to the USPTO until they served no Polycom purpose.

26 FullView has direct personal knowledge of Mr. Rutherford and his co-partners in Polycom’s
27 outside counsel law firm participating in and representing Polycom in (i), (iii), (iv) and (vi).
28

1 57. Polycom has infringed the '711 and '143 Patents by, without authority, consent,
2 right or license, making, using, importing/exporting, offering for sale and/or selling products
3 *worldwide* using the methods, products of methods and apparatuses claimed in these patents in
4 this country. This conduct constitutes infringement under 35 U.S.C. § 271(a) and (g).

5 58. In addition, Polycom has infringed the '711 and '143 Patents in this country,
6 through, *inter alia*, its active inducement of others to make, use, import/export, offer for sale
7 and/or sell the systems, products, methods and products of methods claimed in one or more
8 claims of the '711 Patent and the '143 Patent. This conduct constitutes infringement under
9 35 U.S.C. § 271(b) and (g).

10 59. In addition, Polycom has infringed the '711 and '143 Patents in this country
11 through, *inter alia*, providing and selling goods and services designed for use in practicing one or
12 more claims of the patents, where the goods and services constitute a material part of the
13 invention and are not staple articles of commerce and have no use other than infringing one or
14 more claims of the patents. Polycom has committed these acts with knowledge that the goods
15 and services it provides are specially made for use in a manner that directly infringed the '711
16 and '143 Patents. This conduct constitutes infringement under 35 U.S.C. § 271(c).

17 60. The statute of limitations under 35 U.S.C. § 286 as it applies to any infringement
18 by Polycom is tolled by (a) Polycom's fraudulent concealment of such infringement and (b) the
19 tolling agreement reached between the parties on June 27, 2019 and effective January 23, 2018.

20 61. Polycom's infringing conduct is willful as provided in 35 U.S.C. § 284 and
21 exceptional as provided in 35 U.S.C. § 285.

22 62. As a result of Polycom's infringement, FullView has been damaged.

23
24 WHEREFORE, Plaintiff prays:

- 25 a) That this Court find Polycom has committed acts of patent infringement under the
26 Patent Act, 35 U.S.C. § 271;
27 b) That this Court enter judgment that:
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- 1 (i) The '711 and '143 Patents are valid and enforceable, and
2 (ii) Polycom has willfully infringed the '711 and '143 Patents;
3 c) That this Court award Plaintiff the damages to which it is entitled due to
4 Polycom's patent infringement, with both pre-judgment and post-judgment
5 interest;
6 d) That this Court adjudge Polycom's infringement of the '711 and '143 Patents to
7 be willful and it therefore increase damages to Plaintiff by three times the amount
8 found or assessed pursuant to 35 U.S.C. § 284;
9 e) That this Court adjudge this case to be exceptional and it therefore award Plaintiff
10 its attorney's fees and costs in this action pursuant to 35 U.S.C. § 285; and
11 f) That this Court grant Plaintiff such other and further relief, in law or in equity,
12 both general and special, to which it may be entitled.
13

14 Dated: November 27, 2019

Respectfully submitted,

15 */s/ Bruce Wecker*

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21 *Attorney for Plaintiff FULLVIEW, INC.*
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ECF CERTIFICATION

I, Bruce Wecker, am the ECF user whose ID and password are being used to file this
AMENDED COMPLAINT.

DATED: November 27, 2019

/s/ Bruce J. Wecker

Bruce J. Wecker

EXHIBIT A:

US Patent 6,700,711

Panoramic viewing system
with a composite field of view

(10) Patent No.: US 6,700,711 B2
(45) Date of Patent: *Mar. 2, 2004

(58) **Field of Search** 359/362-363,
359/367, 399, 402-403, 725-732, 831-837;
348/36-39; 353/30, 94, 98-99; 352/69-71

(75) Inventor: **Vishvjit Singh Nalwa**, Holmdel, NJ
(US)

(56) **References Cited**

(73) Assignee: **Fullview, Inc.**, Holmdel, NJ (US)

U.S. PATENT DOCUMENTS

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

5,187,571 A * 2/1993 Braun et al. 358/85

* cited by examiner

This patent is subject to a terminal disclaimer.

Primary Examiner—Thong Nguyen

(21) Appl. No.: 10/093,568

(57) **ABSTRACT**

(22) Filed: Mar. 8, 2002

(65) **Prior Publication Data**

US 2002/0089765 A1 Jul. 11, 2002

Related U.S. Application Data

(63) Continuation of application No. 09/431,400, filed on Dec. 27, 1999, now Pat. No. 6,356,397, which is a continuation of application No. 08/946,443, filed on Oct. 7, 1997, now Pat. No. 6,111,702, which is a continuation-in-part of application No. 08/565,501, filed on Nov. 30, 1995, now Pat. No. 6,115,176.

Cameras are positioned so that at least a portion of the field of view of at least one camera is redirected by a reflective surface. Images from these cameras are merged to produce a composite image while disregarding at least a portion of a camera's field of view such that there is at least one blind region in the composite field of view. Advantageously, such blind regions can be made to encompass edges of mirror surfaces that would otherwise produce image artifacts in the composite image; this can be accomplished without introducing gaps in the angular span of the composite field of view. Data representative of the composite image is stored in a memory from which it may be retrieved selectively using a control means to display a portion of the composite image. The image and control data may be transmitted over a communication network to facilitate remote control and display.

(51) **Int. Cl.**⁷ **G02B 13/06**; G02B 23/08;
H04N 7/00

(52) U.S. Cl. 359/725; 359/363; 359/403;
353/94; 348/36

39 Claims, 8 Drawing Sheets

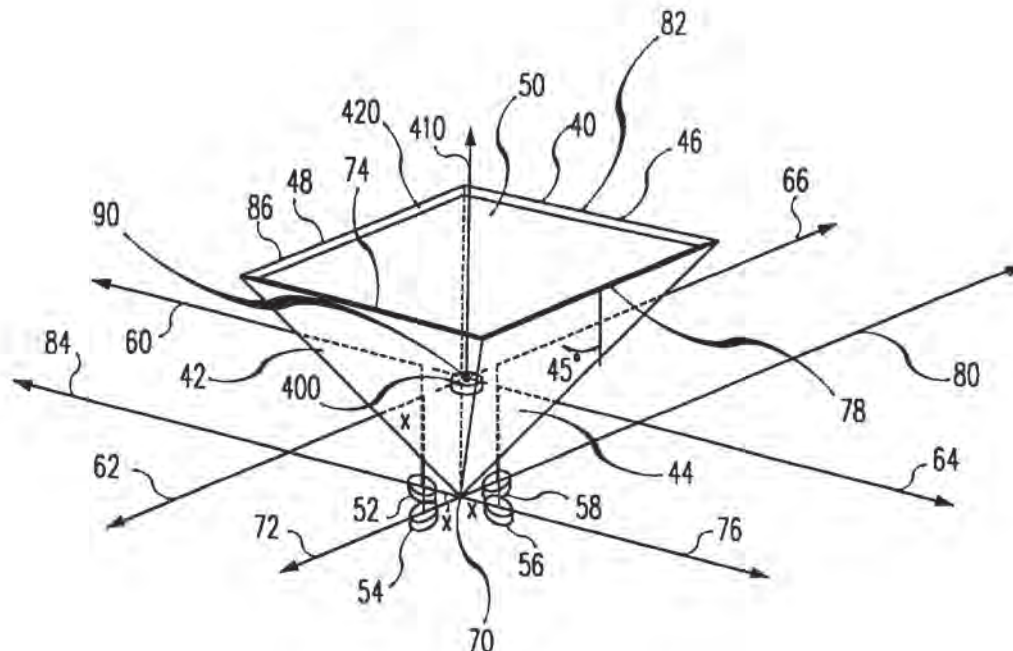


FIG. 1

PRIOR ART

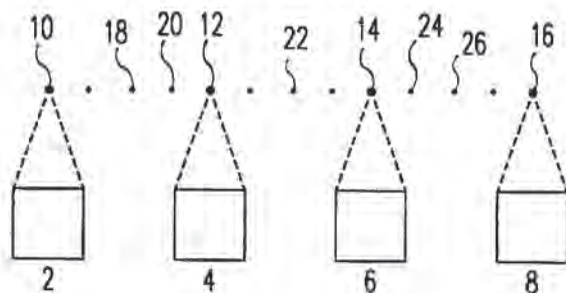


FIG. 2

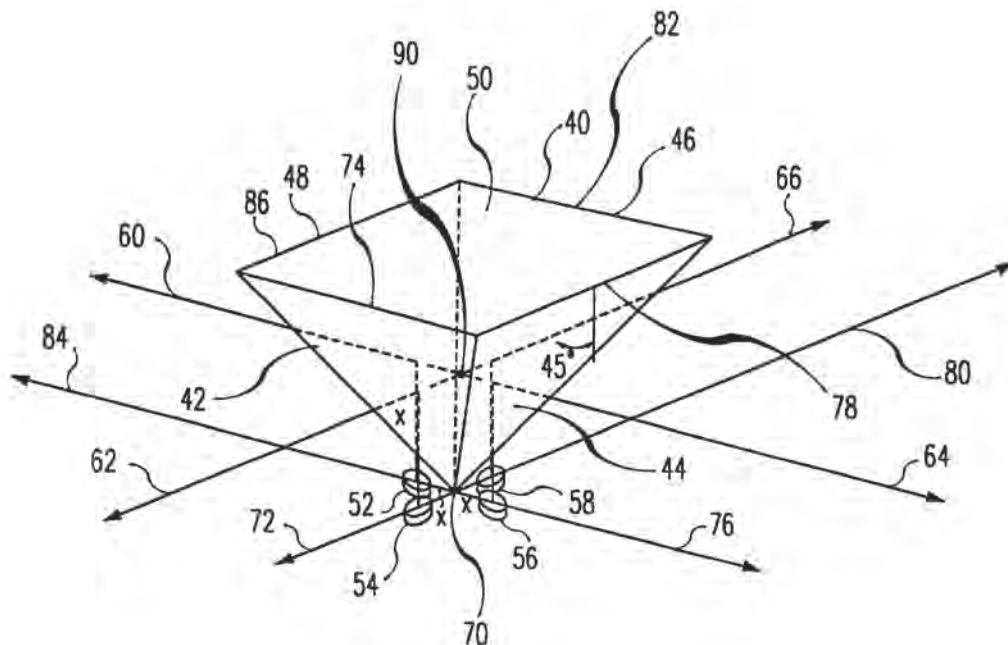


FIG. 3

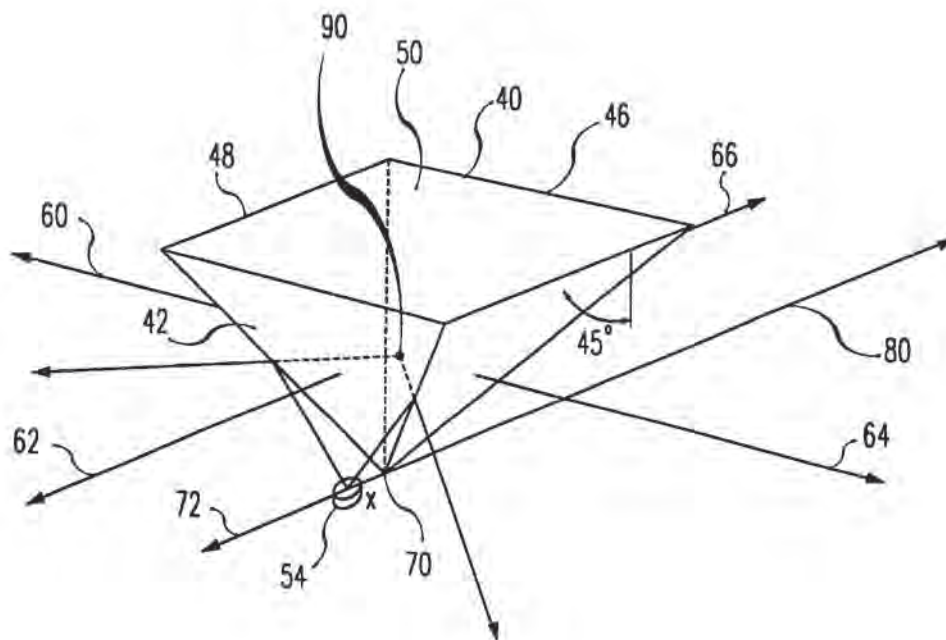


FIG. 4

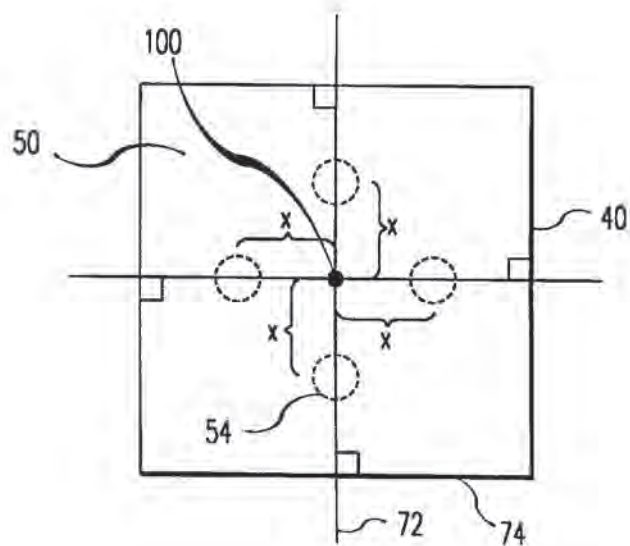


FIG. 5

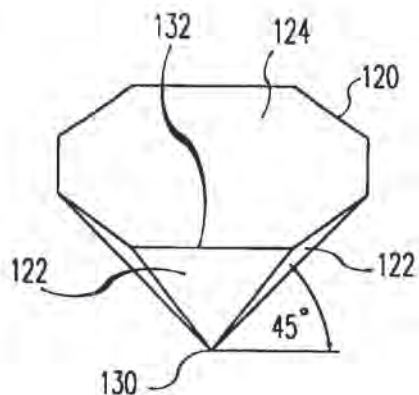


FIG. 6

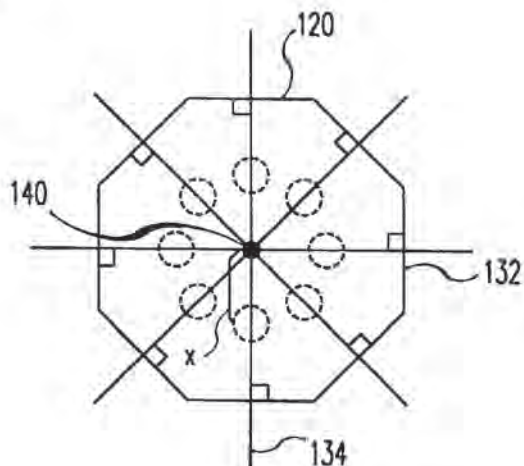


FIG. 7

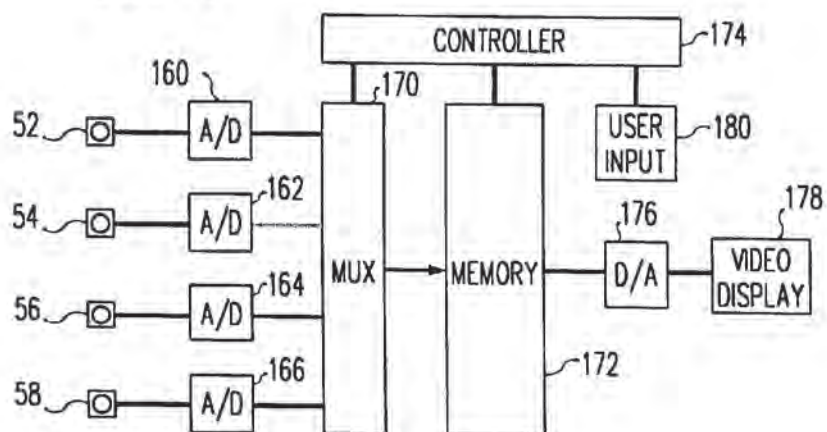


FIG. 8

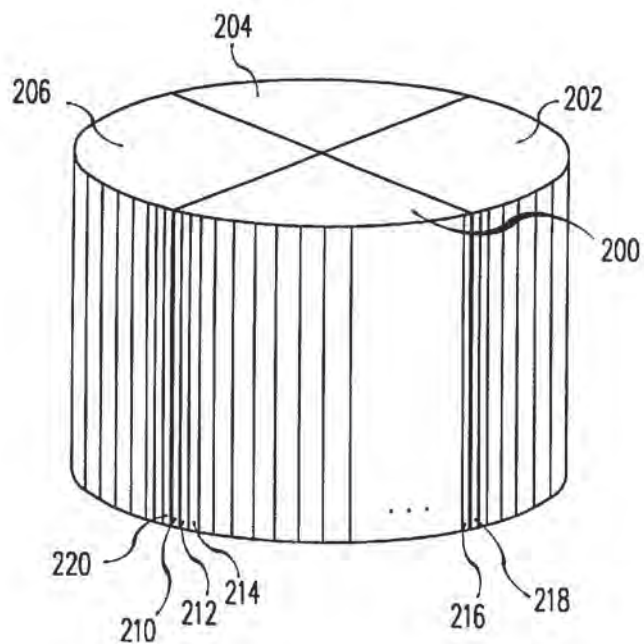


FIG. 9

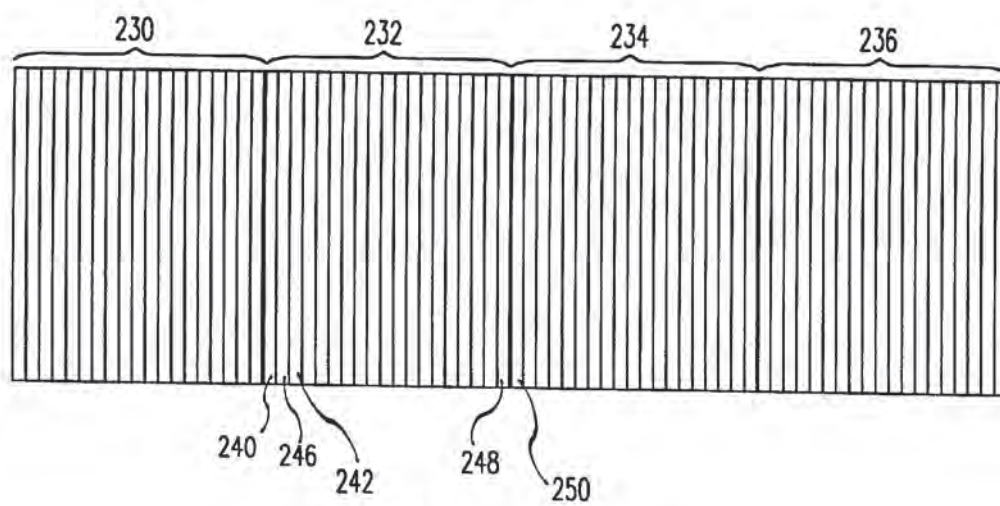


FIG. 10

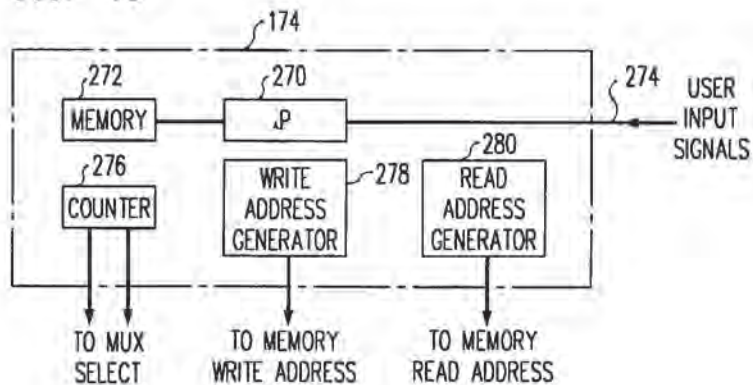


FIG. 11

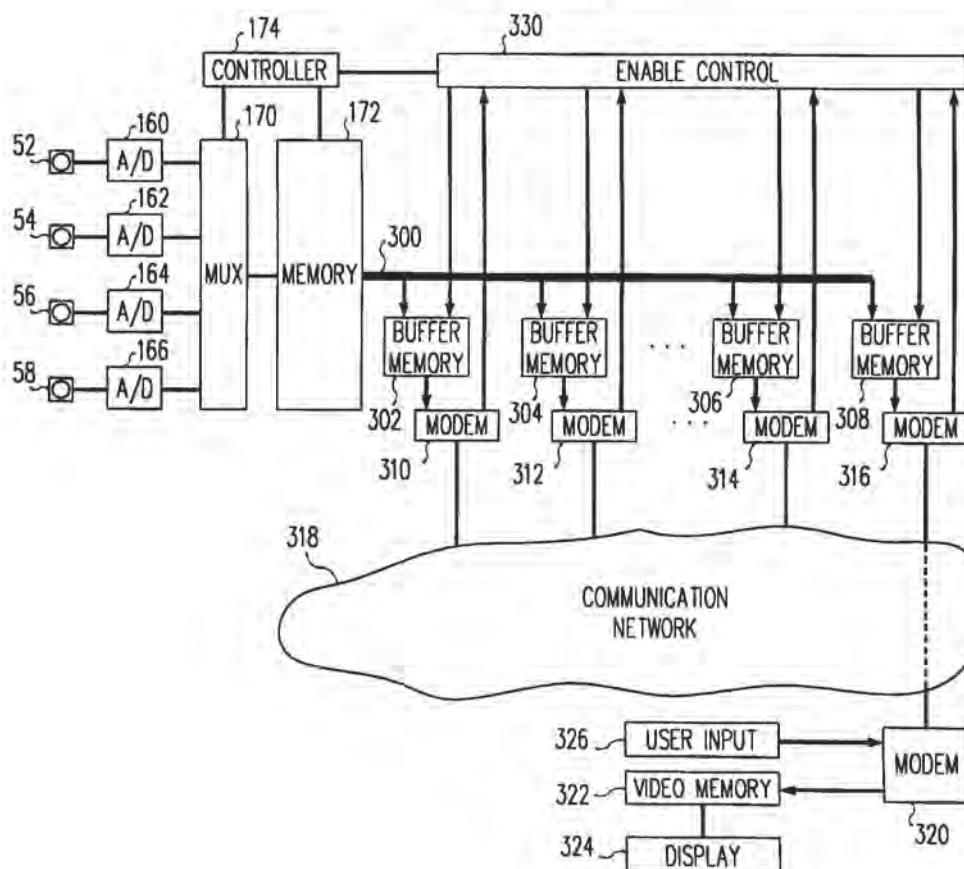


FIG. 12

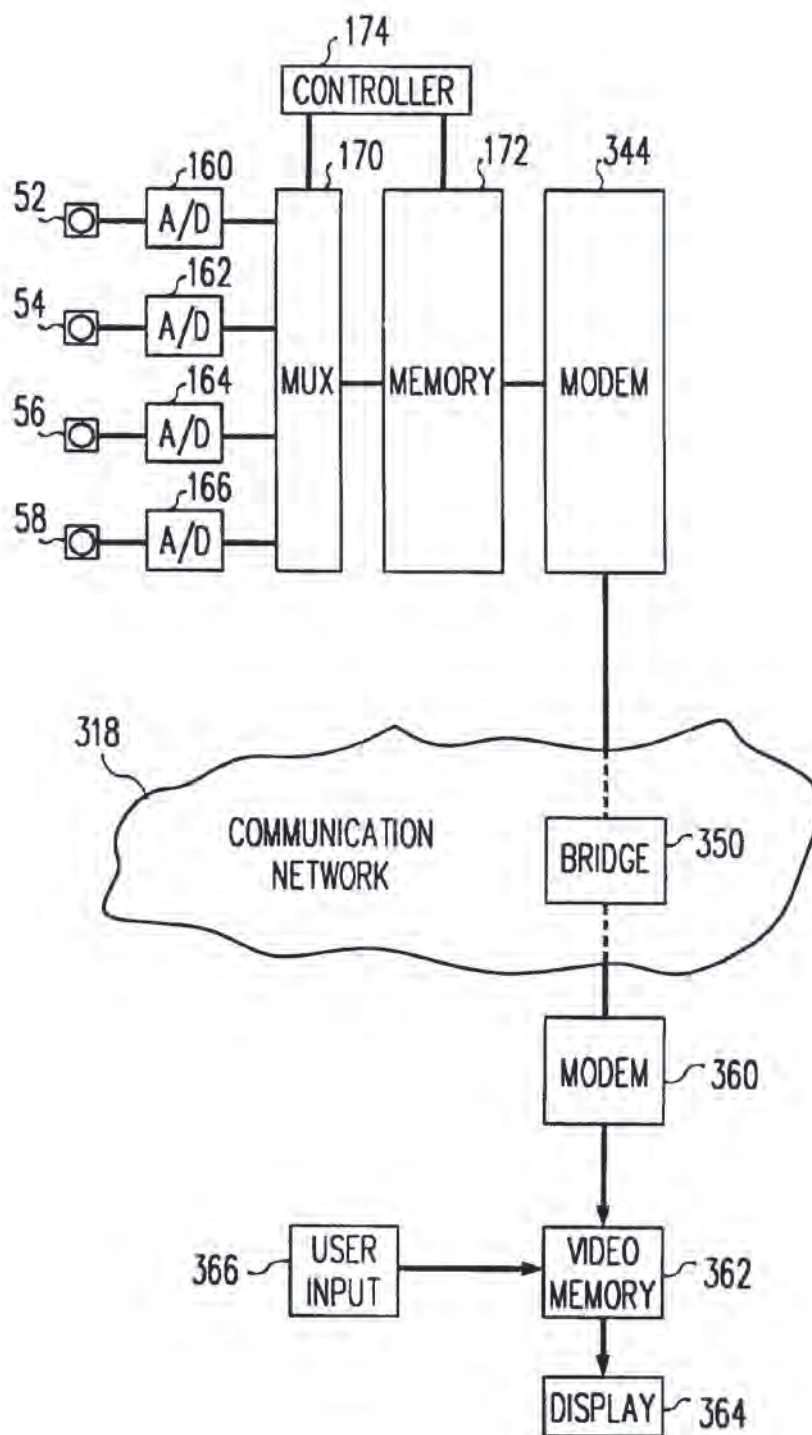


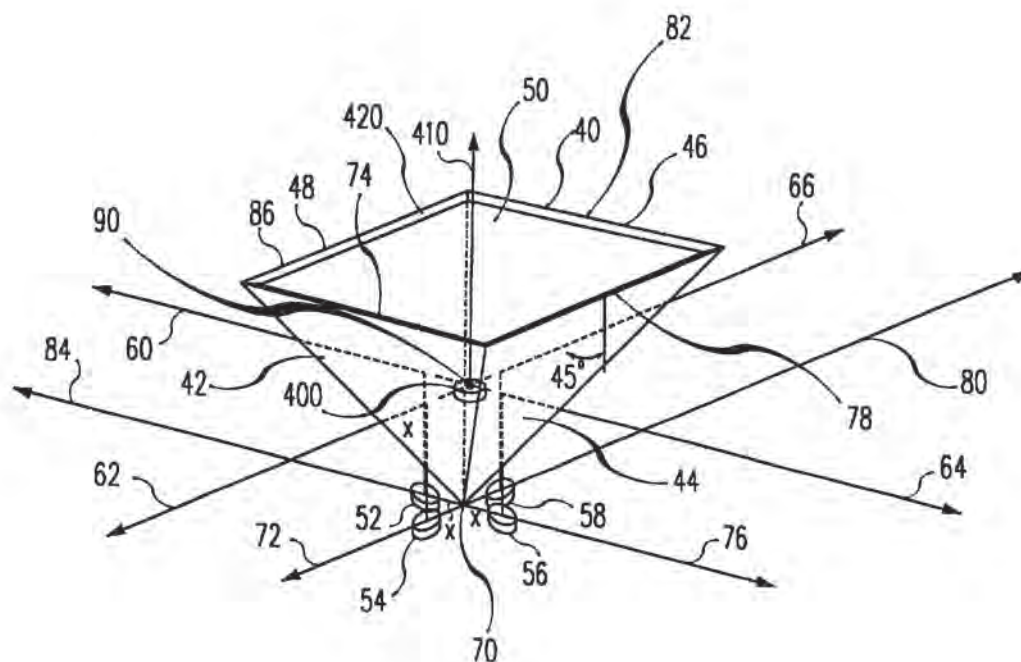
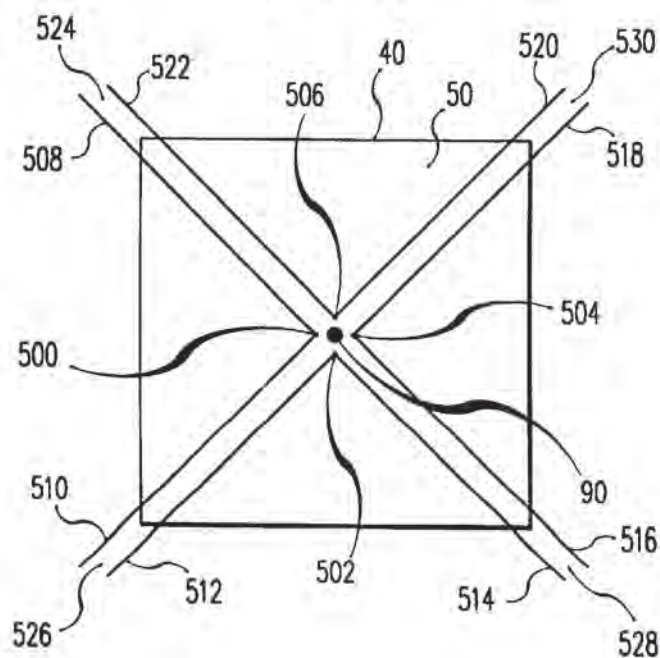
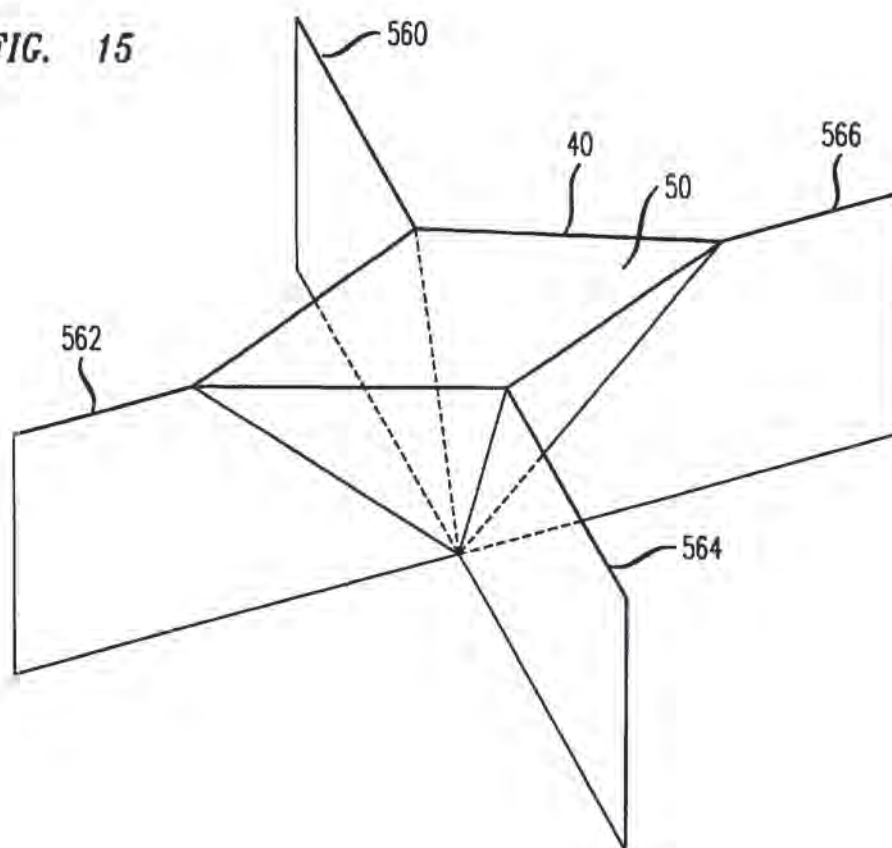
FIG. 13*FIG. 14*

FIG. 15



US 6,700,711 B2

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PANORAMIC VIEWING SYSTEM WITH A COMPOSITE FIELD OF VIEW

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of commonly assigned U.S. Patent application entitled "Panoramic Viewing System With Shades", Ser. No. 09/431,400, filed Dec. 27, 1999, which issued as U.S. Patent No. 6,356,397 on Mar. 12, 2002, which is a continuation of commonly assigned U.S. Patent application entitled "Panoramic Viewing System With Off-set Virtual Optical Centers", Ser. No. 08/946,443, filed Oct. 7, 1997, which issued as U.S. Pat. No. 6,111,702 on Aug. 29, 2000, which is a continuation-in-part of commonly assigned U.S. Patent application entitled "Spherical Viewing/Projection Apparatus", Ser. No. 08/565,501 filed Nov. 30, 1995, which issued as U.S. Pat. No. 6,115,176 on Sep. 5, 2000; and is related to commonly assigned U.S. Patent Application entitled "Panoramic Viewing Apparatus", Ser. No. 08/431,356, filed Apr. 28, 1995, which issued as U.S. Pat. No. 5,745,305 on Apr. 28, 1998 and to commonly assigned U.S. Patent Application entitled "Method and System for Panoramic Viewing", Ser. No. 08/431,354, filed Apr. 28, 1995, which issued as U.S. Pat. No. 5,990,934 on Nov. 23, 1999.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a viewing system; more particularly, a spherical viewing system.

2. Description of the Related Art

In an effort to operate more efficiently, it is desirable to perform some tasks using telepresence. Telepresence refers to providing visual or other types of sensory information from a device at a remote site to a user that make the user feel as if he/she is present at the remote site. For example, many businesses now hold meetings using telepresence. Telepresence is also useful for distance learning and remote viewing of events such as concerts and sporting events. A more realistic telepresence is provided to a user by providing the user with the capability to switch between views, and thereby mimic, for example, looking around a meeting room.

In the past, when several views were made available to a user, several cameras with different optical centers were used. Such a situation is illustrated in FIG. 1. FIG. 1 illustrates cameras 2, 4, 6 and 8 with optical centers 10, 12, 14, and 16, respectively. When the user decided to change views, he or she simply switched between cameras. In more sophisticated systems, when a user decided to change views, he or she was able to obtain a view from optical centers 10, 12, 14, or 16 as well as from additional optical centers 18, 20, 22, 24 or 26. Views associated with optical centers such as 18, 20, 22, 24, and 26 were obtained by using views from the two cameras nearest to the selected optical center. For example, a view from optical center 18 was obtained by using the views from cameras 2 and 4 and interpolating between the two views so as to simulate a view from optical center 18. Such procedures introduced irregularities into views. In addition, forming these interpolated views required a large amount of computational power and time, and thereby made this technique expensive and slow to respond to a user's commands. This computational overhead also limited the number of users that can simultaneously use the system.

Other prior art discloses that the several views made available to a user can also be derived from a single

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wide-angle view that is created from multiple individual views captured by multiple distinct cameras. However, prior-art arrangements to create a single wide-angle view from multiple individual views have been unsatisfactory. In some arrangements, there is substantial parallax between the individual views, parallax that would lead to artifacts where the individual views would overlap or adjoin in any composite image; such artifacts are avoided in some cases by intentionally fragmenting the wide-angle view to have substantial gaps between individual images upon their display (e.g., U.S. Pat. No. 2,942,516). In some other arrangements, even though parallax between individual views may be minimal or absent, image artifacts remain and there is no suggestion on how to prevent these image artifacts from occurring where individual views would adjoin in any composite image (e.g., U.S. Pat. Nos. 3,118,340, 3,356,002, 4,890,314, 5,187,571). In some other arrangements, the number of individual cameras is limited to be no more than three and precise optical alignment of cameras and projectors is required to create a composite wide-angle image that is optical, rather than electronic, for all practical purposes precluding the use of such a composite image in providing multiple views to a user as described above (e.g., U.S. Pat. Nos. 2,931,267, 3,031,920, 4,890,314). Of particular relevance here are prior-art arrangements that use one or more mirrors with more than one camera to create a wide-angle composite image: One problem that has remained unaddressed in such arrangements is how to rid the composite image of image artifacts due to portions of individual images being captured off edges of mirrors (e.g., U.S. Pat. Nos. 2,931,267, 3,031,920, 3,118,340, 4,890,314, 5,187,571); further, even in those of such arrangements in which an attempt is made to reduce other image artifacts, which occur due to causes other than reflection off edges of mirrors and occur where individual images come together in a composite image, the arrangements and techniques proposed are limited to using no more than three cameras and are purely optical rather than electronic, requiring precise optical alignment of cameras and projectors and not lending themselves to providing multiple views to a user as described above (e.g., U.S. Pat. Nos. 2,931,267, 3,031,920). Some other prior art devices have no particular advantage with respect to acquiring a wide-angle field of view and also fail to avoid the above-mentioned image artifacts caused by portions of individual images being captured off edges of mirrors (e.g., U.S. Pat. Nos. 5,016,109, 5,194,959). These are just some of the drawbacks of the prior art that prevent it from being used to create high-quality composite wide-angle images that can be used to provide multiple views to a user as described above.

SUMMARY OF THE INVENTION

One embodiment of the present invention provides an omnidirectional or panoramic viewer where several cameras have a common optical center. The cameras are positioned so that they each view a different reflective surface of a polyhedron such as a pyramid. This results in each camera having a virtual optical center positioned within the pyramid. The field of view of each of the cameras is merged with the individual fields of view of the other cameras and arranged to form a composite field of view which is a continuous 360 degree view of an area when taken as a whole. The user can sweep through 360 degrees of viewing, where each view has the same or nearly the same optical center, by simply using the output of one camera or the combination of two cameras without requiring the computational overhead of interpolation used in the prior art. Such

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an arrangement may be used to enhance use of virtual meeting rooms by allowing a viewer to see the meeting room in a more natural format. This format corresponds closely to a person sitting in the actual meeting who simply turns his or her head to change the view at a particular time.

In another embodiment of the present invention, a nearly spherical view is provided to a user by placing a camera with its optical center at the common virtual optical center of the viewer. In order to enhance the spherical view, the camera at the common virtual optical center may use a wide angle lens.

In still another embodiment of the invention, the cameras are positioned so that their effective optical centers are offset from each other. The offsets produce narrow blind regions that remove image distortions received from the edges of the pyramid's reflective surfaces. Additionally, planar shades that extend in an outward direction are positioned in the blind regions.

In yet another embodiment of the present invention, the viewing device may include any type of image transducer or processing device. If the image transducer or processing device is a camera or other type of image capture device, a panoramic or spherical image is captured for the user, and if the image transducer or processing device is a projector or other type of image producing device, a panoramic or spherical image is produced for the user.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 illustrates a prior art multiple camera viewing system;

FIG. 2 illustrates a four camera omnidirectional or panoramic viewing system using a four-sided pyramid with reflective surfaces;

FIG. 3 illustrates how a reflective surface of the pyramid is used to provide each camera with a common optical center;

FIG. 4 illustrates the top view of the pyramid illustrating the camera positions;

FIG. 5 illustrates an eight-sided pyramid with reflective side surfaces;

FIG. 6 is a top view of the pyramid of FIG. 5;

FIG. 7 is a block diagram of a system to control data produced by the cameras;

FIG. 8 illustrates the association between the data received from the cameras and the view presented to a user;

FIG. 9 illustrates an addressing scheme for the memory of FIG. 7;

FIG. 10 is a block diagram of the controller of FIG. 7;

FIG. 11 illustrates using a telecommunications network to provide a selection of views to a plurality of users;

FIG. 12 illustrates a second embodiment for providing a selection of views to multiple users over a telecommunications network;

FIG. 13 illustrates the viewing system of FIG. 2 with a fifth camera;

FIG. 14 illustrates a top view of the pyramid of FIG. 2 with displaced virtual optical centers; and

FIG. 15 illustrates the pyramid of FIG. 14 with shades positioned in blind regions.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 2 illustrates a four camera system for providing a 360 degree view to a user, where the cameras each have a

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common virtual optical center within the pyramid. Pyramid 40 has reflective sides 42, 44, 46 and 48 and may be a hollow or solid structure. In a preferred embodiment, each of the reflective sides forms a 45 degree angle with a plane parallel to base 50 and passing through the vertex of pyramid 40. Cameras 52, 54, 56 and 58 are associated with pyramid reflective surfaces 48, 42, 44, and 46, respectively. The cameras may be image gathering devices such as an optical scanner. As a result, camera 52 views a reflection from surface 48 to enable it to view objects in the direction of arrow 60. Camera 54 views a reflection from surface 42 to view objects in the direction of arrow 62. Camera 56 views a reflection from surface 44 to view objects in the direction of arrow 64, and camera 58 views a reflection from surface 46 to view objects in the direction of arrow 66. Each camera has a 90 degree field of view. The combination of the four cameras viewing reflections from their associated reflective surfaces on pyramid 40, produce a 360 degree view of the area surrounding pyramid 40. It is desirable to locate the optical center of each camera on a plane that is parallel to base 50 and intersects vertex 70 of pyramid 40. Each camera's optical center should also be located on a line that passes through vertex 70 and is perpendicular to the base line of the camera's associated reflective surface. For example, the optical center of camera 54 is located on line 72. Line 72 is perpendicular to base line 74 of reflective surface 42. Line 72 is in a plane that passes through vertex 70 and is parallel to base 50. Likewise, the optical center of camera 56 is positioned on line 76 which is perpendicular to baseline 78, the optical center of camera 58 is positioned on line 80 which is perpendicular to base line 82, and the optical center of camera 52 is positioned on base line 84 which is perpendicular to base line 86.

Each camera optical center is positioned on one of the above described lines at a distance X from vertex 70 and each camera has its optical axes or direction of view pointing perpendicular to base 50. (The distance X should be such that the reflective surface reflects as much of the camera's field of view as desired; however, the defects in the reflective surface become more visible when the camera is moved closer to the reflective surface.) This positioning of optical centers results in the cameras sharing a virtual optical center located at position 90. Virtual optical center 90 is located a distance X from the vertex 70 on a line that passes through vertex 70 and is perpendicular to base 50.

FIG. 3 illustrates another view of pyramid 40 where only camera 54 is shown for the sake of simplicity. Camera 54 is positioned on line 72 so as to have a virtual optical center at position 90 within pyramid 40. If camera 54 has a 90 degree field of view in the direction perpendicular to base 50, and if the optical center of camera 54 is at a distance of X from vertex 70 along line 72, camera 54 has a 90 degree view in the direction of arrow 62. In similar fashion, cameras 56, 58, and 52 have 90 degree views in the direction of arrows 64, 66, and 60, respectively. This arrangement inexpensively produces a 360 degree field of view of an area because cameras with a 90 degree field of view have relatively inexpensive optics.

FIG. 4 is a top view of pyramid 40. FIG. 4 illustrates the placement of the optical center of camera 54 along line 72. Line 72 should be in a plane that passes through vertex 70 and is parallel to base 50. The line should also be perpendicular to base line 74 of pyramid 40. The camera's optical center should be positioned a distance X from vertex 70 along line 72. The distance X should be such that the reflective surface reflects as much of the camera's field of view as desired. Point 100 is located on base 50 at a position

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where a line from vertex 70 perpendicularly intersects base 50. In a similar fashion, the optical centers of cameras 56, 58 and 52 are positioned the distance X along lines 76, 80 and 84, respectively.

FIG. 5 illustrates an eight-sided pyramid 120. Pyramid 120 has reflective surfaces 122 where each of surfaces 122 forms a 45 degree angle with a plane that passes through vertex 130 and is parallel to base 124. As with the four-sided pyramid of FIG. 2, each reflective surface of FIG. 5 may have a camera associated with it. Each camera's optical center is positioned on a line that is in a plane that passes through vertex 130 and is parallel to base 124. The line is perpendicular to base line 132 of the reflective surface associated with the camera to be positioned. Using an eight-sided pyramid offers the advantage of using cameras with only a 45 degree field of view to obtain a 360 degree view. Cameras with only a 45 degree field of view have inexpensive optics and enable a 360 degree view to be constructed using relatively inexpensive components.

FIG. 6 is a top view of pyramid 120. As discussed with regard to FIG. 5, each camera's optical center is positioned along a line 134 which is in a plane that passes through vertex 130 and is parallel to base 124. The optical centers are positioned a distance X along line 134 which is perpendicular to the appropriate base line 132. Point 140 is on base 124 at the point of intersection between base 124 and a line that passes through vertex 130 and is perpendicular to base 124.

Pyramids having more or less reflective sides may be used. The advantage of using pyramids having a large number of sides is that cameras with moderate to small fields of view may be used. Cameras with moderate fields of view have relatively inexpensive optics. The number of sides used in a pyramid is somewhat limited by the cost of providing a large number of cameras. A 360 degree view of a scene may be provided using a pyramid having three reflective sides. It may be expensive to use only a three-sided pyramid in order to provide a 360 degree field of view. This embodiment of the invention uses three cameras each with a 120 degree field of view, and cameras with such a wide field of view use relatively expensive optical components.

In applications where a full 360 degree view is not desired, it is possible to build a viewer that does not have a camera associated with each reflective surface of the pyramid.

FIG. 7 illustrates a block diagram of a system for controlling data produced by the cameras of a viewing device such as the viewing device described in FIGS. 2 through 4. Cameras 52, 54, 56 and 58 obtain a 360 degree view of an area via their associated reflective surfaces of pyramid 40. The image signal or output signal of cameras 52, 54, 56 and 58 are passed through analog to digital converters (A/D) 160, 162, 164, and 166, respectively. The output of the cameras can be thought of as a stream of pixels and the output of the A/Ds can be thought of as data representative of the pixels from the cameras. The output of the A/Ds are passed through mux 170. Mux 170 allows the pixel data from each of the A/Ds to reach memory 172. Controller 174 cycles the select lines of mux 170 so that the outputs of all of the A/Ds are stored in memory 172. Mux 170 is switched at a rate that is four times the pixel rate of the cameras. If more or less cameras are used, the rate at which mux 170 is switched will be increased or slowed accordingly. It is also possible to eliminate mux 170 and to store the output of each A/D in a separate memory. Controller 174 is implemented using a microprocessor which provides control signals to counters that control the switching of mux 170 and counters

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used to provide addressing to memory 172. The control signals to the counters include reset, enable and a starting offset.

As a result of the pixel information being passed to memory 172, memory 172 contains a 360 degree view of a scene. Pixel information stored in memory 172 is passed through digital to analog converter (D/A) 176 and to video display 178. The actual portion of memory 172 that is passed to video display 178 via D/A 176 is controlled via user input device 180. User input device 180 may be a common device such as a mouse, joystick, or keyboard. The user may simply lean a joystick to the right to shift his view to the right, lean the joystick to the left to shift the view to the left, or leave the joystick in the center to keep the view unchanged. Based on the input from user device 180, controller 174 varies offsets and starting addresses that are used to provide addressing to memory 172.

FIG. 8 illustrates the relationship between the data provided by the cameras and the view available to the user. Since the cameras share a virtual optical center, the view can be thought of as a cylindrical view. Sector 200 can be thought of as representing the information provided by camera 52, sector 202 can be thought of as representing the information provided by camera 54, sector 204 can be thought of as representing the information provided by camera 56, and sector 206 can be thought of as representing the information provided by camera 58. The surface of the cylinder in each sector can be thought of as a collection of columns, where each column is composed of pixels. For example, sector 200 can be thought of as a collection of columns including columns 210, 212, 214 and 216. Likewise, the output produced by camera 54 can be thought of as a collection of columns which include column 218 in sector 202 and the output of camera 58 can include columns such as column 220 in sector 206. The column of pixels near the sector boundaries are closer together than the columns near the center of a sector. This occurs because the cameras capture the image on a plane while FIG. 8 shows the columns projected onto a cylindrical surface.

FIG. 9 illustrates how memory 172 is divided to provide easy access to different views based on signals from user input device 180. Sections 230, 232, 234 and 236 correspond to sectors 206, 200, 202 and 204, respectively. Each of sections 230, 232, 234 and 236 can be thought of as a block within memory 172. The blocks in memory 172 are broken into columns of sequential addresses. The first column of memory segment 230 corresponds to the first column of pixels of sector 206. The number of memory positions associated with a column should be at least sufficient to have one location for each pixel in a particular column. For example, if a column of pixels from FIG. 8 includes 1000 pixels, each column associated with the memory segments of FIG. 9 should have at least 1000 locations. The number of columns associated with a particular memory segment should be at least equal to the number of columns associated with a particular section of the cylinder of FIG. 8.

If a camera scans in a horizontal direction, sequential pixels are written in adjacent columns, but possibly different rows, of a particular memory segment by simply changing an offset to a counter generated address. The overall write address is generated by adding the offset to the counter's output. This offset is changed at the rate in which the horizontally scanned pixels are received. After a horizontal scan is completed, the counter is incremented and once again the offsets are changed at the horizontal scan rate. As a result, when addressing a particular segment of memory during a write cycle, the columns are addressed by changing

the offset at the horizontal pixel scan rate, and incrementing the counter at the vertical scan rate. This type of addressing scheme is used for accessing columns within each memory segment. When addressing different memory segments during a write cycle, a write segment offset is added to the sum of the counter output and the column offset. The write segment offset permits addressing memory segments 230, 232, 234, and 236. The segment offset is changed at the same rate as mux 170 is switched.

Pixel data is read from memory 172 in a similar fashion. The sum of a counter output and two sets of offsets are used to generate a read address. Once an initial starting column has been picked, the read address is generated by switching a read column offset at a rate that is equal to the horizontal scan rate of a video display. After reading one horizontal scans worth of data, the read counter is incremented and the read column offsets are changed at a rate equal to the horizontal scan rate of the display. As a result, the offset addresses are changing at the display's horizontal display rate and the counter is incremented at a rate equal to the vertical scan rate of a display. It is possible to read data out at a rate faster or slower than required by the video display; however, if read out faster, a buffer memory should be used, if read out slower the video display may appear choppy to the viewer.

It should be noted that the cylindrical arrangement of pixels of FIG. 8 is typically displayed on a flat or nearly flat display. As a result, the image is displayed by compensating for converting between a cylindrical surface and a flat surface. This may be carried out using a simple conversion algorithm within a common digital signal processing integrated circuit. Methods for these types of conversions are well known in the art and can be found in "A Guided Tour of Computer Vision," Vishvjit S. Nalwa, Addison-Wesley Publishing Co., Reading, Mass., 1993. It is also possible to carry out the conversion using a very high resolution display.

It should be noted that if the view selected by a user corresponds exactly to the view of a particular camera, such as camera 52, columns 240-248 are read from memory 170. Column 240 is the first column in segment 232 and column 248 is the last column in segment 232. If the user decides to move the view in a counter-clockwise direction, the start column will shift to the right so that the read operation begins at column 246 and ends at column 250. It should be noted that column 246 is the second column associated with memory segment 232 which has the pixel data from camera 52, and that column 250 is the first column of pixel data associated with camera 56. As the user shifts the view, the starting column shifts in relationship to the user's commands. For example, if the user indicates that the view should shift in a counter-clockwise direction, the start column of FIG. 9 moves to the right, similarly, if the viewer indicates that the view should shift in a clockwise direction, the start column shifts to the left. As before, columns are addressed by using offsets, if the offsets involve moving between memory segments, a read segment offset is added to the sum of the column offset and counter output.

It should be recalled that the columns near the sector boundaries of FIG. 8 are closer together. As a result, when the user commands a change in a view and when the border of that view is near a sector boundary, the start column changes by a larger number of columns for a given angular rotation of the view. Conversely, when the border of the view is near the center of the sector, the start column changes by a smaller number of columns for a given angular rotation.

FIG. 10 illustrates a block diagram of controller 174. Controller 174 includes microprocessor 270 and memory

272. Memory 272 includes RAM and ROM. Processor 270 receives commands on line 274 from user input device 180. Microprocessor 270 controls start, stop and reset of counter 276. Counter 276 controls the select lines of mux 170. Counter 276 counts at a rate that is four times the horizontal scan rate of the cameras. Write address generator 278 provides write addressing for memory 172. Write address generator 278 includes a counter, register for storing offsets and adder for adding the offsets and counter output. Microprocessor 270 controls the offset selection and the counters used by write address generator 278. The write addresses are formed as described with regard to FIG. 9. Read address generator 280 provides read addresses to memory 172. Read address generator 280 includes a counter, register for storing offsets and adder for adding the offsets and counter output. As with write address generator 278, microprocessor 270 controls the offset selection and the counters of read address generator 280. Microprocessor 270 also controls the starting column used by the counters based on inputs provided on line 274 from user input 180.

The write and read addresses are provided to memory 172 separately if memory 172 is implemented using a two port memory. If memory 172 is implemented with a single port memory, the write and read addresses are multiplexed to memory 172.

FIG. 11 illustrates an embodiment where a panoramic viewer is used to provide views to several users over a communications network. In this embodiment, all of the columns of pixel data are read from memory 172 and placed on bus 300. Buffer memories 302, 304, 306 and 308 receive the data from bus 300. The buffer memories are enabled only when desired columns are available on bus 300. The buffer memories then pass their information to modems 310, 312, 314 and 316, which then provide the pixel data to telecommunications network 318. Telecommunications network 318 then delivers the information from the modems to the users. In one example, a user receives information from modem 316 using modem 320. Modem 320 then provides the pixel information that was in memory 308 to a local video memory 322. Video memory provides the pixel information to display 324 for viewing. The user at this location controls the view using user input device 326 which may be a device such as a mouse, keyboard or joystick. Modem 320 transmits the user input device signals over telecommunications network 318 to modem 316 which then provides the signals to enable controller 330. Enable controller 330 receives a signal from controller 174 that indicates which column is being read from memory 172. When the appropriate column is available, the enable controller 330 enables the buffer memory 308 to receive the columns of data specified by the user input device signals received over the communication network. As discussed with regard to FIG. 9, enable controller 330 simply moves the start column based on signals from the user input device. In this embodiment, enable controller 330 enables the input to the buffer memory when the pixel data from the start column is on bus 300. Enable controller 330 disables the input to the buffer memory when the total number of columns of pixels to be viewed are provided to the buffer memory. FIG. 11 illustrates a system where four users can individually control their viewing; however, more users may be accommodated by simply increasing the number of buffer memories, modems, and ports on enable controller 330.

FIG. 12 illustrates another embodiment in which multiple viewers can use the panoramic viewer. As the pixel data is read from memory 172, all of the data is passed over telecommunications network 318 to telecommunications

bridge 350. The information from memory 172 is provided to bridge 350 via modem 344; however, the data may be passed to bridge 350 without use of modem 344 if a digital connection is made between memory 172 and bridge 350. Bridge 350 then distributes all of the data received from memory 172 to each user in communication with bridge 350. If bridge 350 provides analog link to users, a modem should be used at each user port. If the bridge has a digital link to the user ports, a modem is not required. In the case of an analog link, the data from memory 172 passes from modem 344 via bridge 350 to modem 360 at a user port. Modem 360 passes the pixel data to video memory 362. Video memory 362 then passes the pixel information to video display 364 under control of a user via user input device 366. User input device may be a mouse, joystick or computer keyboard. In this embodiment, the entire contents of memory 172 is fed to video memory 362. The data read from memory 362 and passed to video display 364 is controlled using user input device 366 in a fashion similar to that which was described with regard to FIG. 9.

FIG. 13 illustrates the viewing system of FIG. 2 with a fifth camera. Camera or image gathering device 400 is located in pyramid 40 with the optical center of camera 400 located at virtual optical center 90. Camera 400 views objects in the direction of arrow 410. It is desirable to provide camera 400 with a wide angle lens. The resulting wide angle view coupled with the views of the remaining four cameras, provides a nearly spherical view. If the cameras of FIG. 13 are replaced with image producing devices, the nearly spherical viewing system becomes a nearly spherical projection system. It should be noted that a camera or projection device may be placed at the virtual optical center of viewing/projection devices having pyramids with three, four or more sides. It should also be noted that edges 420 of the reflective surfaces should be beveled to avoid undesirable obstruction of camera 400's field of view. It is also possible to avoid undesirable image artifacts from base edges 420 by moving camera or image processing device 400. Device 400 should be moved so that device 400's optical center is positioned away from virtual optical center 90 in the direction of arrow 410. Device 400's optical center should be positioned so that the device's field of view does not include edges 420.

FIG. 14 illustrates a top view of the pyramid of FIG. 2. In reference to FIG. 2, camera 52, 54, 56 and 58 have been moved upward in the direction of base 50. As a result, virtual optical centers 500, 502, 504 and 506, which correspond to cameras 52, 54, 56 and 58, respectively, are moved away from virtual optical center 90. It is desirable to move the virtual optical centers so that camera 52 captures an image between lines 508 and 510, camera 54 captures an image between lines 512 and 514, camera 56 captures an image between lines 516 and 518, and camera 58 captures an image between lines 520 and 522. This results in the cameras not capturing useful images from narrow planar shaped regions. In particular, planar regions 524, 526, 528 and 530 are not used by the cameras and form blind regions. This offers the advantage of removing portions of the cameras' fields of view that are received from the edges of the reflective pyramid. Eliminating these portions of the fields of view alleviates the need to provide image processing that compensates for image artifacts at the edges. It is desirable to keep virtual optical centers 500, 502, 504 and 506 closely clustered so that planes 524, 526, 528 and 530 are only as thin as necessary to avoid edge artifacts. By maintaining such thin planes, the need to process the images at their common boundaries is removed while minimizing the noticeable effect seen by a user.

From the foregoing description, it is readily apparent that moving the virtual optical centers outward, as in FIG. 14, facilitates the creation of a composite image that excludes images of mirror edges lying between portions of the fields of view of individual cameras. From the geometry that has been described, it is apparent that the mirror edges lie within, or are encompassed by, the blind regions of the composite field of view corresponding to the composite image. It is also apparent that the narrow planar shaped blind regions lie between portions of adjacent individual fields of view that extend outwardly in substantially similar directions, and that these blind regions do not expand in size with increasing distance from the viewing system. Such expansion of the blind regions would be undesirable because it would allow them to envelope objects that are increasingly large with increasing distance from the viewing system. As described earlier in reference to FIG. 7, the individual images, and the composite image, are stored as data in memory 172. Accordingly, eliminating portions of the individual fields of view corresponding to the blind regions of the composite field of view, as described above with reference to FIG. 14, results in a collection of stored data in memory 172 that excludes data representing images of mirror edges that lie within the blind regions, and it will be immediately apparent to those skilled in the art that the described exclusion of images of mirror edges from useful camera images may be accomplished by disregarding in memory 172, or discarding from this memory, image data that corresponds to portions of the fields of view of the cameras that contain these mirror edges.

FIG. 15 illustrates the pyramid of FIG. 14 with shades 560, 562, 564 and 566 positioned in planar regions 524, 526, 528, and 530, respectively. The shades reduce the amount of unwanted light that enters the cameras. Similar shades may be placed in blind regions between device 400's field of view and one or more of the other image processing devices' field of view. For example, if we recall that moving image device 400 in the direction of arrow 410 removes base edges 420 from the device's field of view, a shade may be placed in one or more of the planar blind regions that extend out from a base edge 420.

What is claimed is:

1. A method of producing a composite image with a plurality of sensors each having an individual field of view, comprising the steps of:

for at least one of the plurality of sensors, redirecting at least a portion of its individual field of view with a reflective area; and

merging images corresponding to the individual fields of view to produce the composite image having a corresponding field of view, wherein each one of at least two fields of view corresponding to images that are merged has a portion, where the images are merged, that has viewing directions that are substantially similar to the viewing directions of the other portion, and wherein the viewing directions within each one of such two portions appear to originate substantially from a point that is offset from the point for the other one of such two portions.

2. The method of claim 1, wherein the field of view corresponding to the composite image has at least one blind region that encompasses at least a portion of an edge of a reflective area and that lies between the two portions of the two individual fields of view.

3. The method of claim 2, wherein the number of sensors each of whose field of view is redirected at least in part by a reflective area is at least three.

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4. The method of claim 2, wherein the number of sensors each of whose field of view is redirected at least in part by a reflective area is at least five.

5. The method of claim 1, wherein images corresponding to the individual fields of view are merged electronically by merging data representative of the fields of view to produce data representative of the composite image and data representative of the composite image is stored by electronic means.

6. The method of claim 5, further comprising displaying the composite image selectively using a control means to select a portion of the composite image to be displayed.

7. The method of claim 6, wherein the number of sensors each of whose field of view is redirected at least in part by a reflective area is at least three.

8. The method of claim 6, wherein the number of sensors each of whose field of view is redirected at least in part by a reflective area is at least five.

9. The method of claim 5, further comprising displaying at least a portion of the composite image remotely after transmitting this portion over a communication network.

10. The method of claim 9, wherein the number of sensors each of whose field of view is redirected at least in part by a reflective area is at least three.

11. The method of claim 9, wherein the number of sensors each of whose field of view is redirected at least in part by a reflective area is at least five.

12. The method of claim 5, wherein the number of sensors each of whose field of view is redirected at least in part by a reflective area is at least three.

13. The method of claim 5, wherein the number of sensors each of whose field of view is redirected at least in part by a reflective area is at least five.

14. The method of claim 1, wherein the number of sensors each of whose field of view is redirected at least in part by a reflective area is at least three.

15. The method of claim 1, wherein the number of sensors each of whose field of view is redirected at least in part by a reflective area is at least five.

16. A viewing apparatus having a composite field of view, comprising:

at least two image sensors, each having an individual field of view;

at least one reflective area that redirects at least part of the individual field of view associated with one of the image sensors,

the individual fields of view of at least two image sensors being merged to produce the composite field of view, at least portions of each of the two individual merged fields of view having substantially similar viewing directions where they are merged, and the merged fields of view creating in the composite field of view at least one blind region that encompasses at least a portion of an edge of the reflective area and that lies between portions of two individual fields of view; and

a memory for storing data representative of said composite field of view electronically.

17. The viewing apparatus of claim 16, wherein the number of sensors each of whose individual field of view is redirected at least in part by a reflective area is at least three.

18. The viewing apparatus of claim 16, wherein the number of sensors each of whose individual field of view is redirected at least in part by a reflective area is at least five.

19. A viewing apparatus having a composite field of view, comprising:

at least two image sensors, each having an individual field of view;

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at least one reflective area that redirects at least part of the individual field of view associated with one of the image sensors,

the individual fields of view of at least two image sensors being merged to produce the composite field of view, at least portions of each of the two merged individual fields of view having substantially similar viewing directions where they are merged, and the merged fields of view creating in the composite field of view at least one blind region that encompasses at least a portion of an edge of the reflective area and that lies between portions of two individual fields of view;

a memory for storing data representative of said composite field of view electronically; and

control means for selectively retrieving said data from said memory in response to user signals produced in response to a user's input.

20. The viewing apparatus of claim 19, wherein the number of sensors each of whose individual field of view is redirected at least in part by a reflective area is at least three.

21. The viewing apparatus of claim 19, wherein the number of sensors each of whose individual field of view is redirected at least in part by a reflective area is at least five.

22. A viewing apparatus having a composite field of view, comprising:

at least two image sensors, each having an individual field of view; at least one reflective area that redirects at least part of the individual field of view associated with one of the image sensors,

the individual fields of view of at least two image sensors being merged to produce the composite field of view, at least portions of each of the two merged individual fields of view having substantially similar viewing directions where they are merged, and the merged fields of view creating in the composite field of view at least one blind region that encompasses at least a portion of an edge of the reflective area and that lies between portions of two individual fields of view;

a memory for storing data representative of said composite field of view electronically;

control means for selectively retrieving said data from said memory in response to user signals produced in response to a user's input; and

communication network interface means for transmitting said data retrieved from said memory over a communications network and for receiving said user signals over said communications network.

23. The viewing apparatus of claim 22, wherein the number of sensors each of whose individual field of view is redirected at least in part by a reflective area is at least three.

24. The viewing apparatus of claim 22, wherein the number of sensors each of whose individual field of view is redirected at least in part by a reflective area is at least five.

25. A composite image produced with a plurality of sensors each having an individual field of view, by following the method of:

for at least one of the plurality of sensors, redirecting at least a portion of its individual field of view with a reflective area; and

merging images corresponding to the individual fields of view to produce the composite image having a corresponding field of view, wherein each one of at least two fields of view corresponding to images that are merged has a portion, where the images are merged, that has viewing directions that are substantially similar to the

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viewing directions of the other portion, and wherein the viewing directions within each one of such two portions appear to originate substantially from a point that is offset from the point for the other one of such two portions.

26. The composite image of claim 25, wherein the field of view corresponding to the composite image has at least one blind region that encompasses at least a portion of an edge of a reflective area and that lies between the two portions of the two individual fields of view.

27. The method of claim 26 wherein the number of sensors each of whose field of view is redirected at least in part by a reflective area is at least three.

28. The method of claim 26 wherein the number of sensors each of whose field of view is redirected at least in part by a reflective area is at least five.

29. The composite image of claim 25, wherein images corresponding to the individual fields of view are merged electronically by merging data representative of the fields of view to produce data representative of the composite image and data representative of the composite image is stored by electron means.

30. The composite image of claim 29, wherein a portion of the composite image is displayed selectively using a control means to select the portion of the composite image to be displayed.

31. The method of claim 30 wherein the number of sensors each of whose field of view is redirected at least in part by a reflective area is at least three.

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32. The method of claim 30 wherein the number of sensors each of whose field of view is redirected at least in part by a reflective area is at least five.

33. The composite image of claim 29, wherein at least a portion of the composite image is displayed remotely after this portion is transmitted over a communication network.

34. The method of claim 33 wherein the number of sensors each of whose field of view is redirected at least in part by a reflective area is at least three.

35. The method of claim 33 wherein the number of sensors each of whose field of view is redirected at least in part by a reflective area is at least five.

36. The method of claim 29 wherein the number of sensors each of whose field of view is redirected at least in part by a reflective area is at least three.

37. The method of claim 29 wherein the number of sensors each of whose field of view is redirected at least in part by a reflective area is at least five.

38. The method of claim 25, wherein the number of sensors each of whose field of view is redirected at least in part by a reflective area is at least three.

39. The method of claim 25, wherein the number of sensors each of whose field of view is redirected at least in part by a reflective area is at least five.

* * * * *

EXHIBIT B:
US Patent 6,128,143
Panoramic viewing system
with support stand

United States Patent [19]

Nalwa

[11] **Patent Number:** **6,128,143**[45] **Date of Patent:** **Oct. 3, 2000**[54] **PANORAMIC VIEWING SYSTEM WITH SUPPORT STAND**[75] Inventor: **Vishvjit Singh Nalwa**, Middletown, N.J.[73] Assignee: **Lucent Technologies Inc.**, Murray Hill, N.J.[21] Appl. No.: **09/141,883**[22] Filed: **Aug. 28, 1998**[51] **Int. Cl.⁷** **G02B 13/06**; G03B 37/04; H04N 7/00[52] **U.S. Cl.** **359/725**; 359/363; 359/403; 353/94; 348/39[58] **Field of Search** 359/363-367, 359/402-406, 431, 618, 627, 629, 725-731, 831, 834-836; 348/14-15, 36, 218, 264, 39; 353/30, 37, 94, 98-99[56] **References Cited****U.S. PATENT DOCUMENTS**

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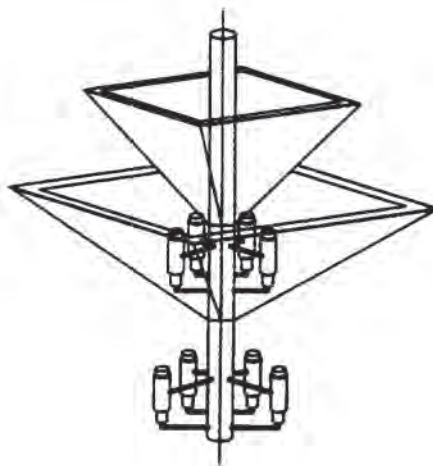
Starchild: Galaxies, XP002124075, Nov. 1999.

Primary Examiner—Thong Nguyen

Attorney, Agent, or Firm—Christopher N. Malvone

[57] **ABSTRACT**

A compact high resolution omnidirectional or panoramic viewer has several cameras with a common virtual optical center. The field of view of each of the cameras is arranged to form a continuous 360 degree view of an area when taken as a whole. The cameras are positioned so that they each views a different reflective surface of a polyhedron such as a pyramid. This results in each camera having a virtual optical center positioned within the pyramid. The cameras may be positioned so that their virtual optical centers are offset from each other. The offsets produce narrow blind regions that remove image distortions received from the edges of the pyramid's reflective surfaces. The reflective pyramids may be stacked base to base or nested within each other to produce a more compact panoramic viewer. Using two or more reflective pyramids in such close proximity permits using many cameras with the same virtual optical center. Using many cameras divides a large viewing area into many smaller areas where an individual camera views each smaller area. Since each camera views a smaller area, increased resolution is provided to the user. The pyramids are mounted to a post that passes through their vertices, and the cameras are secured to the portion of the post extending out of the vertices.

18 Claims, 12 Drawing Sheets

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FIG. 1

PRIOR ART

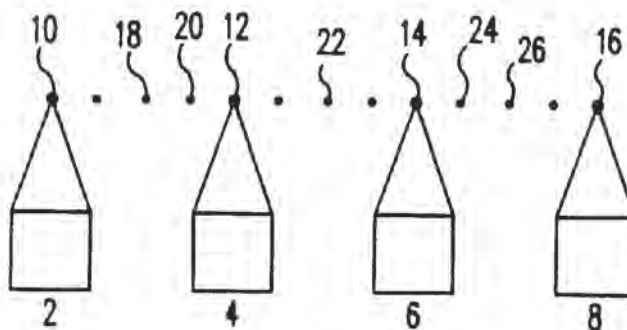


FIG. 2

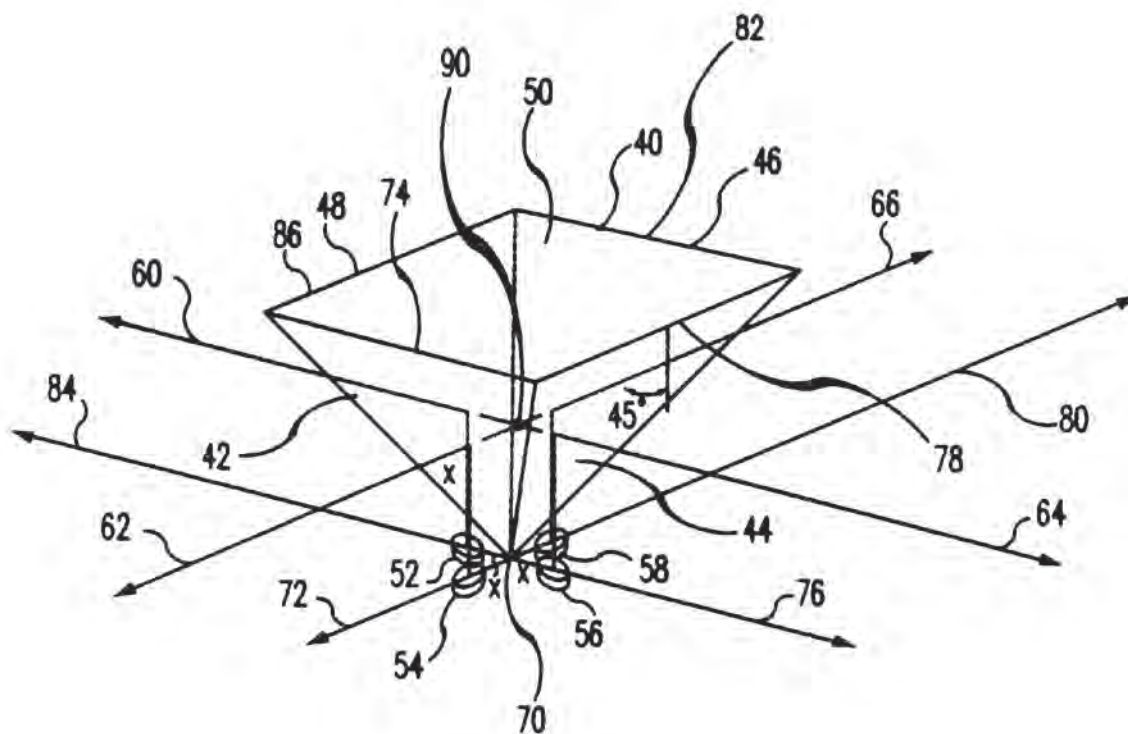


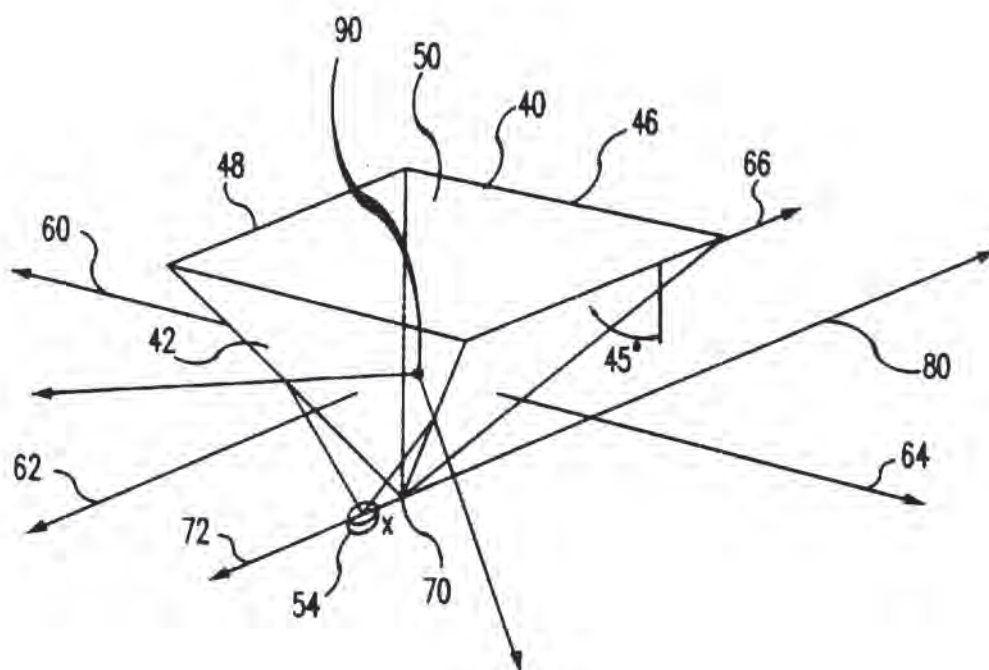
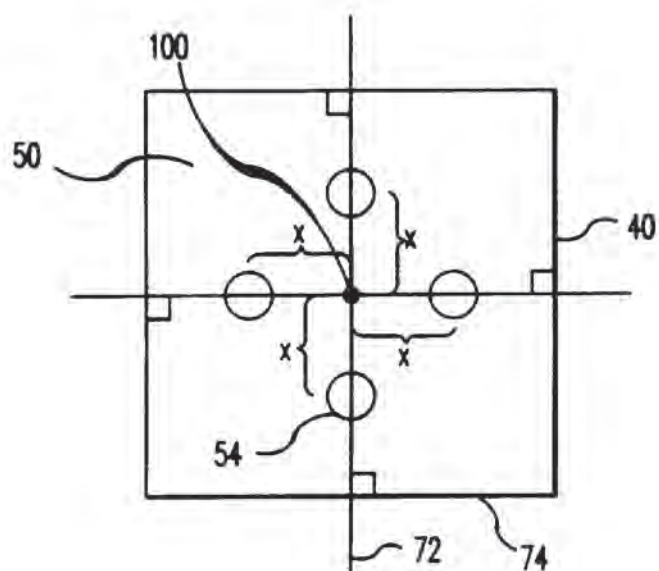
FIG. 3**FIG. 4**

FIG. 5

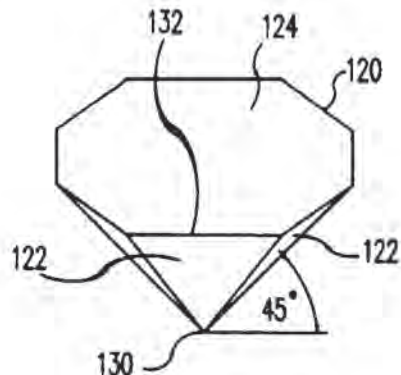


FIG. 6

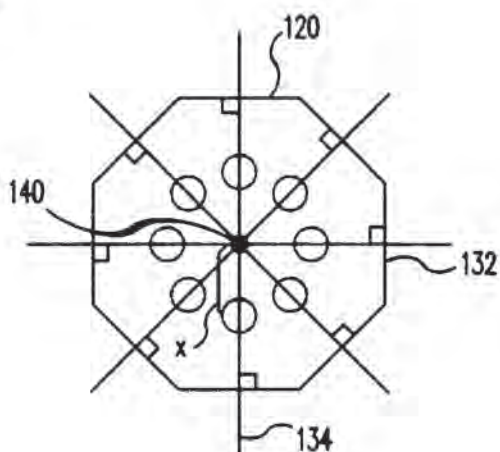


FIG. 7

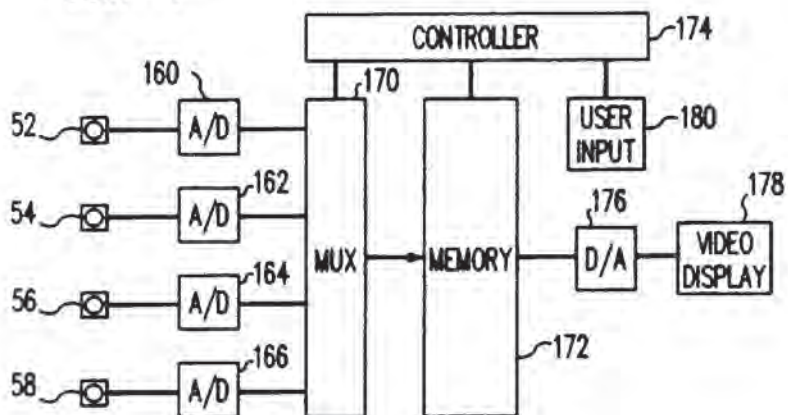


FIG. 8

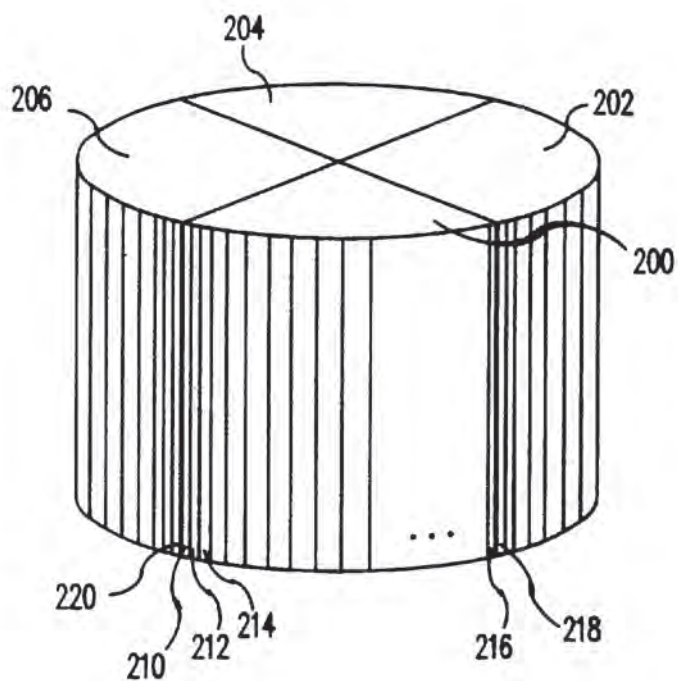


FIG. 9

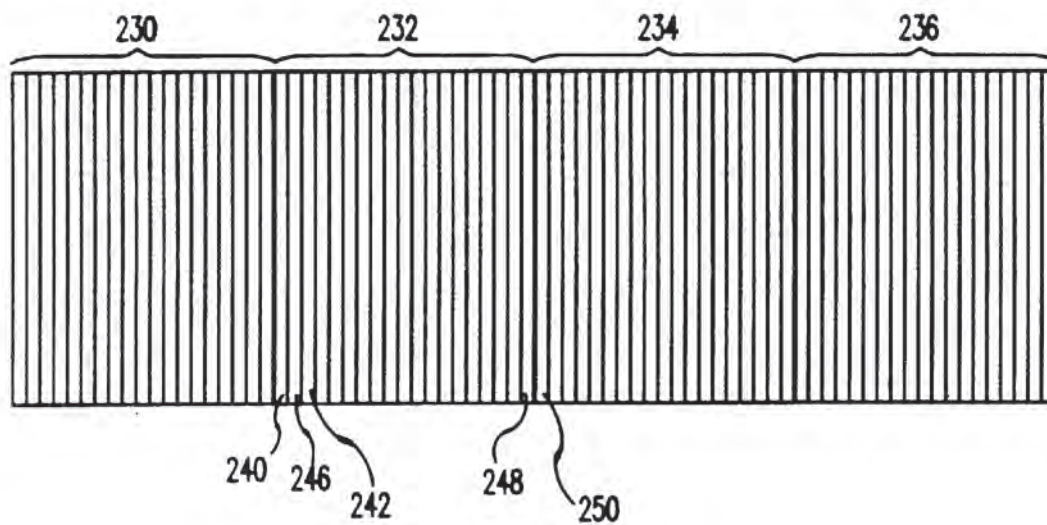


FIG. 10

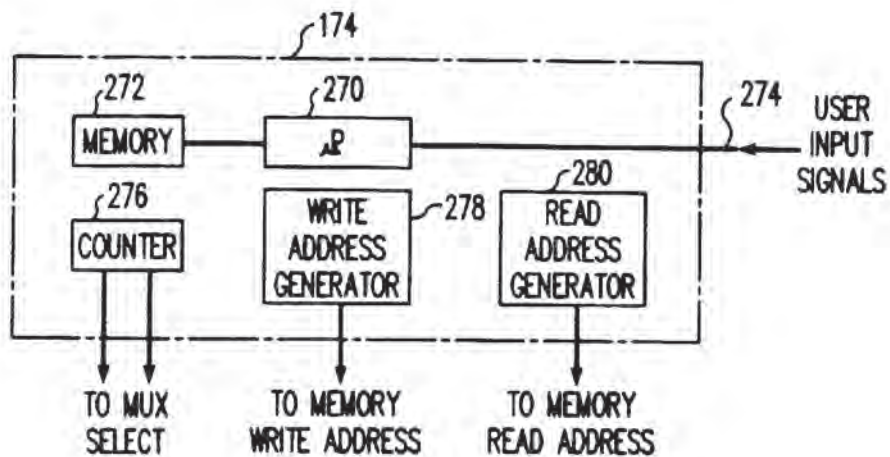


FIG. 11

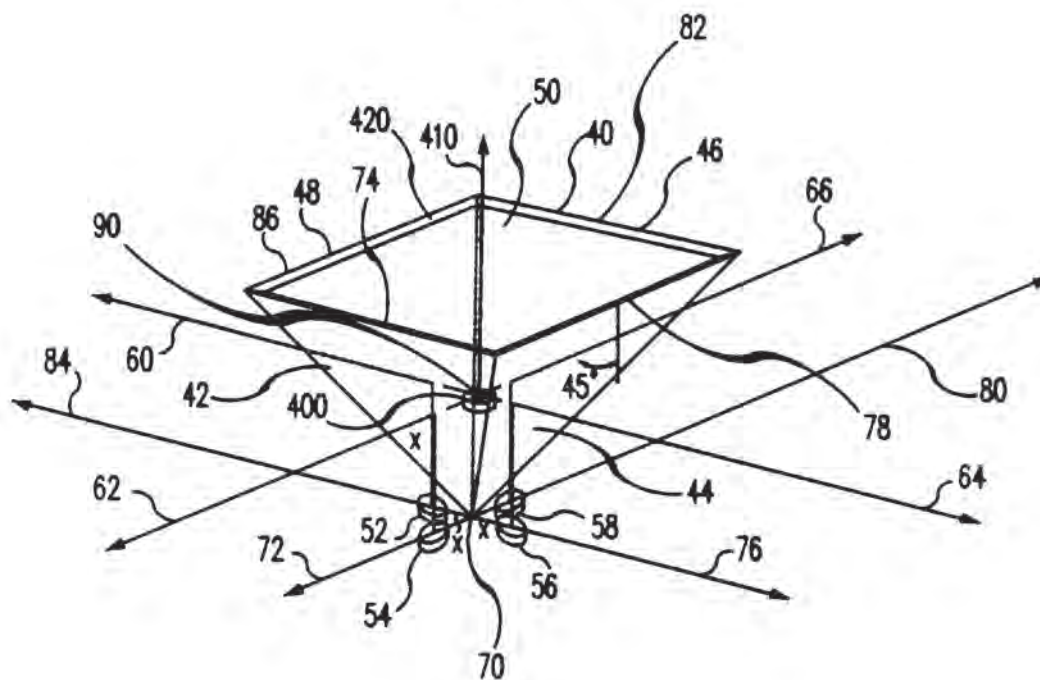


FIG. 12

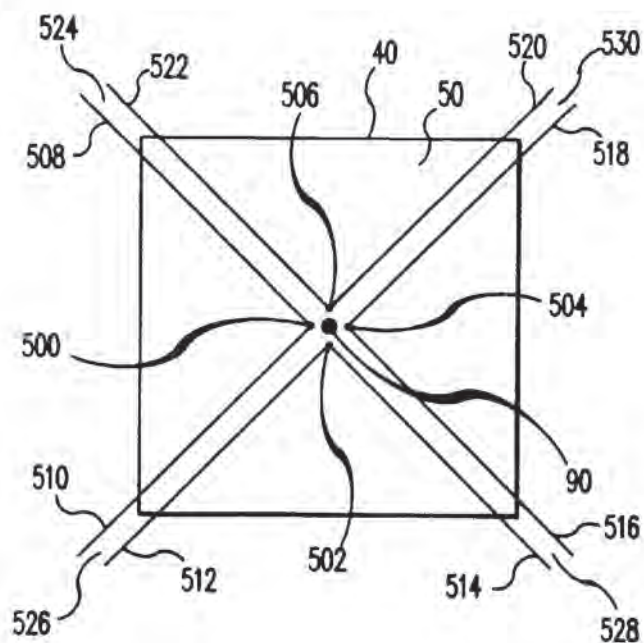


FIG. 13

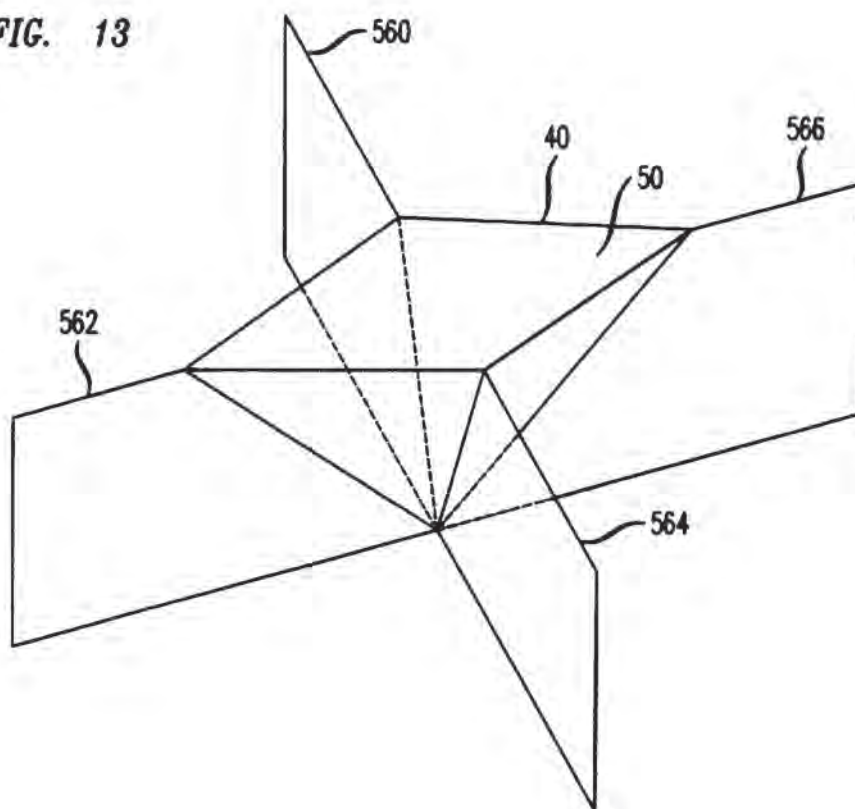


FIG. 14

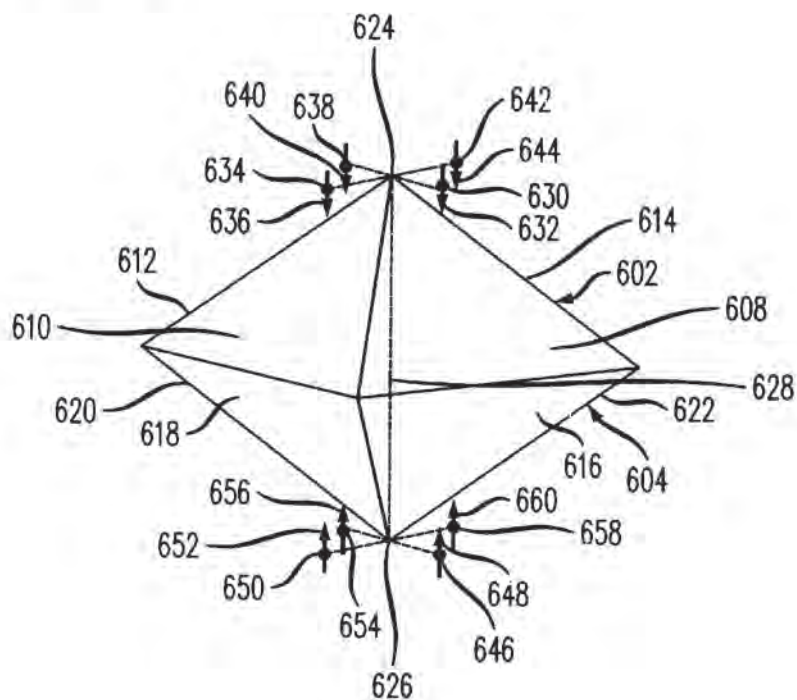


FIG. 15

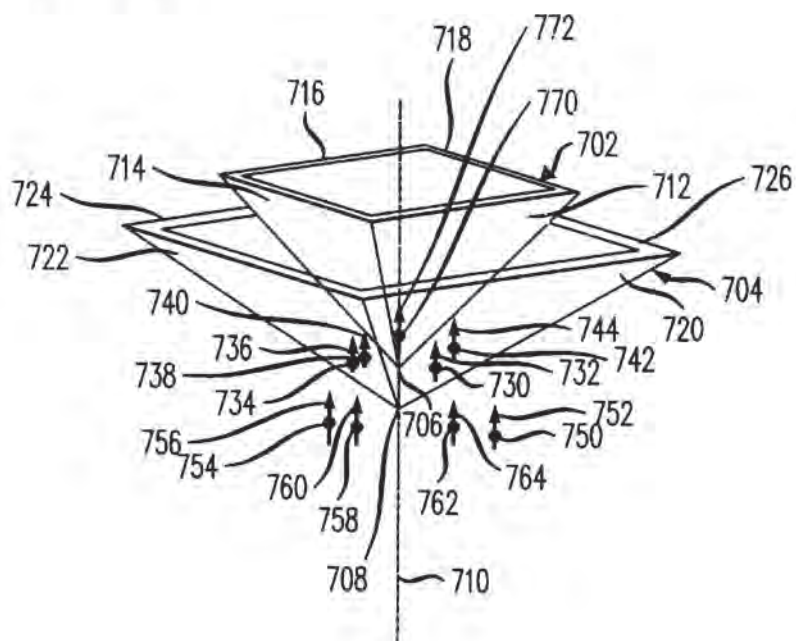


FIG. 16

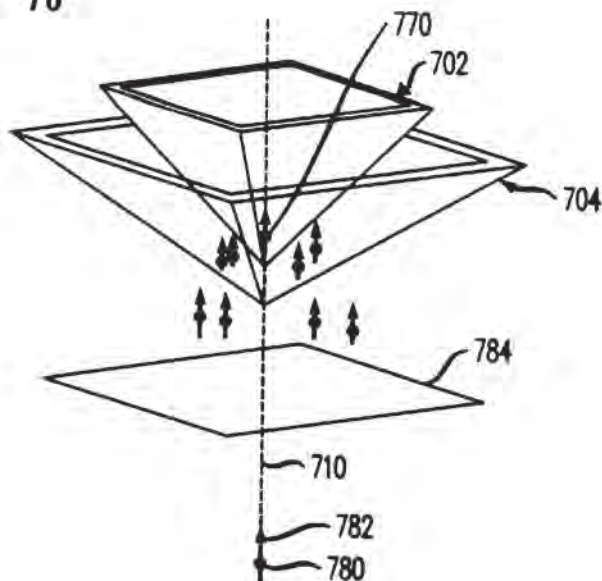


FIG. 17

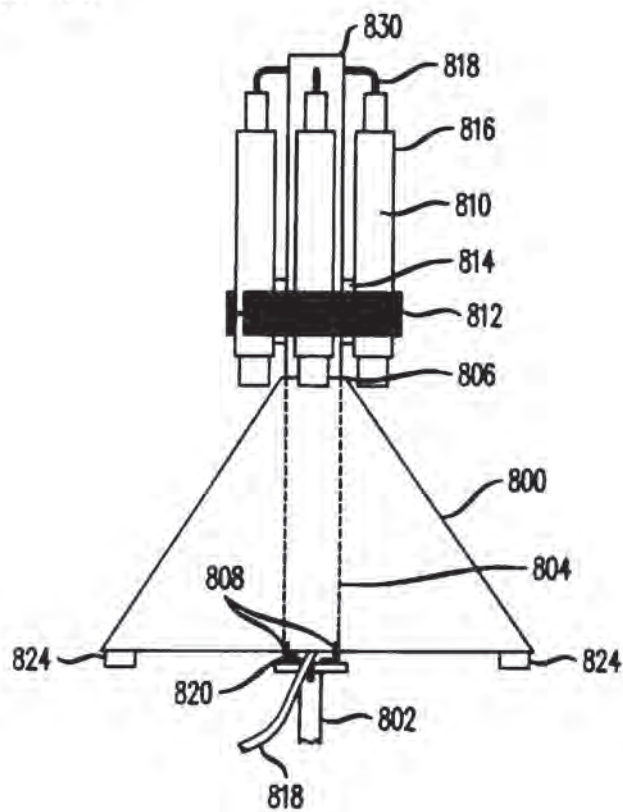


FIG. 18

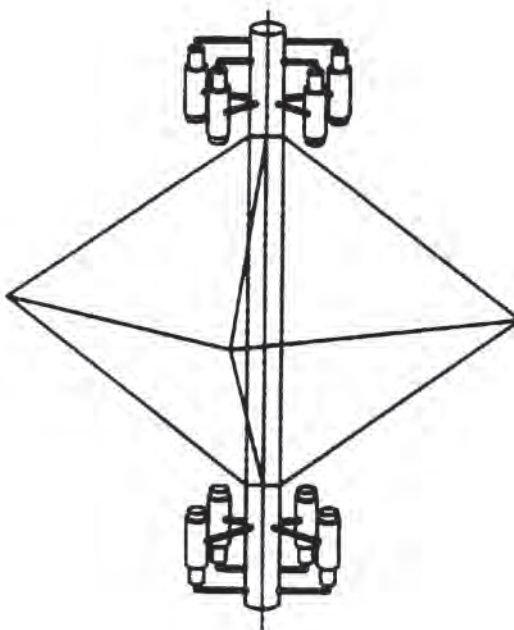


FIG. 19

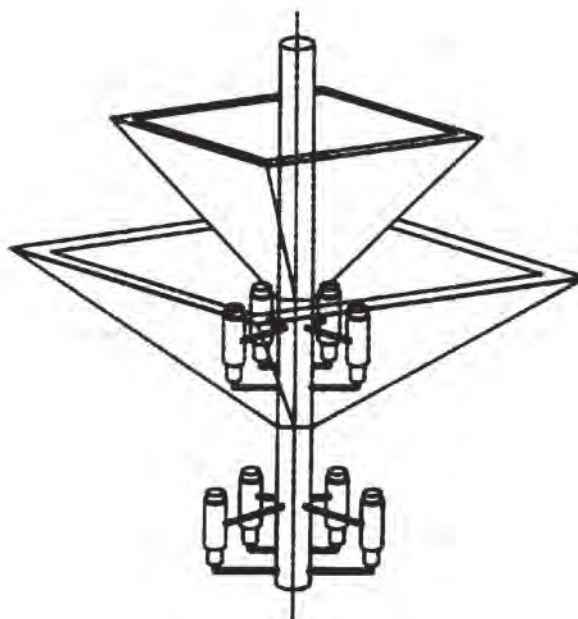


FIG. 20

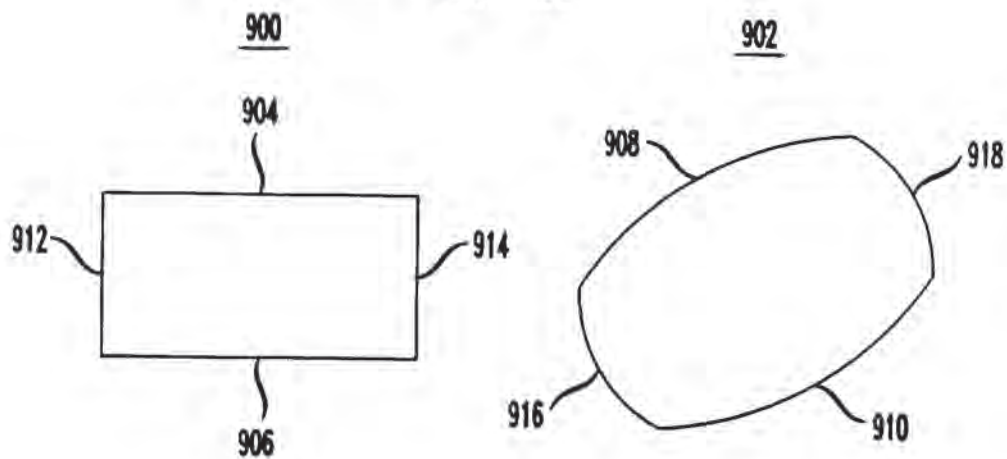
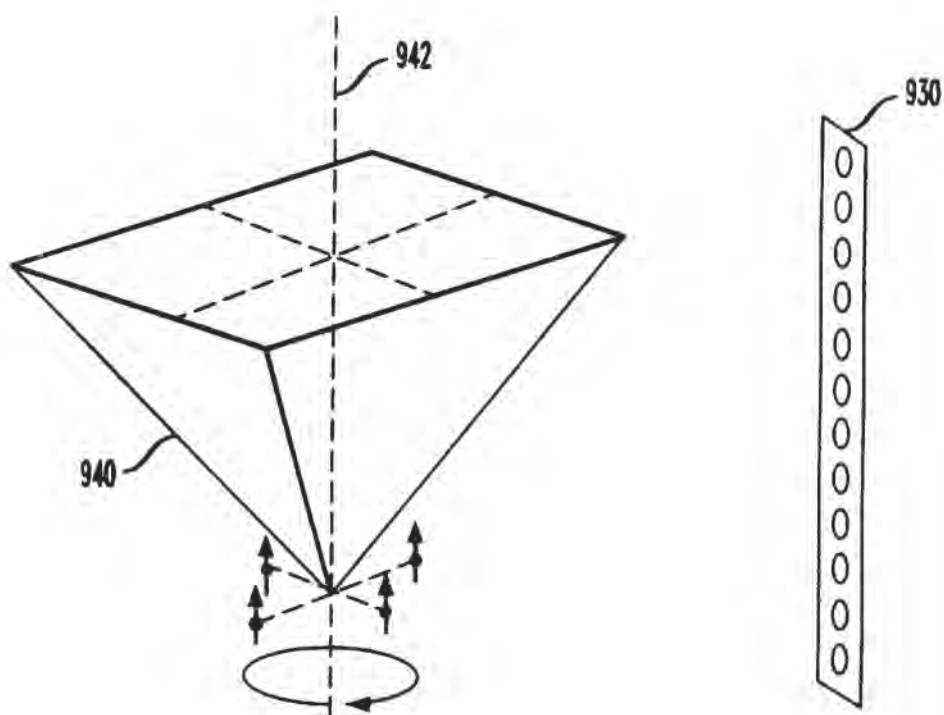


FIG. 21



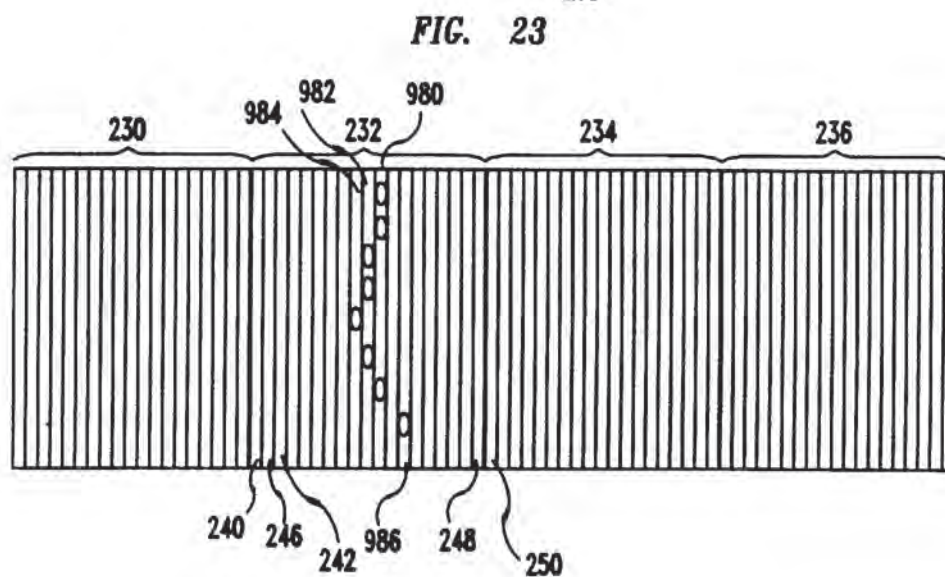
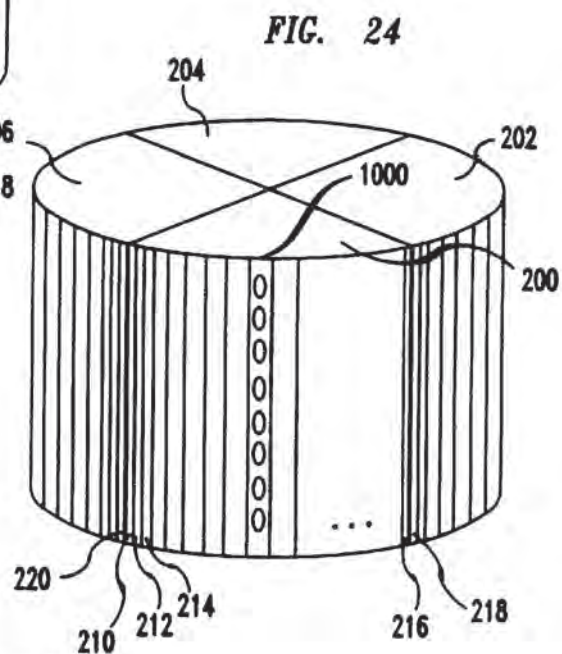
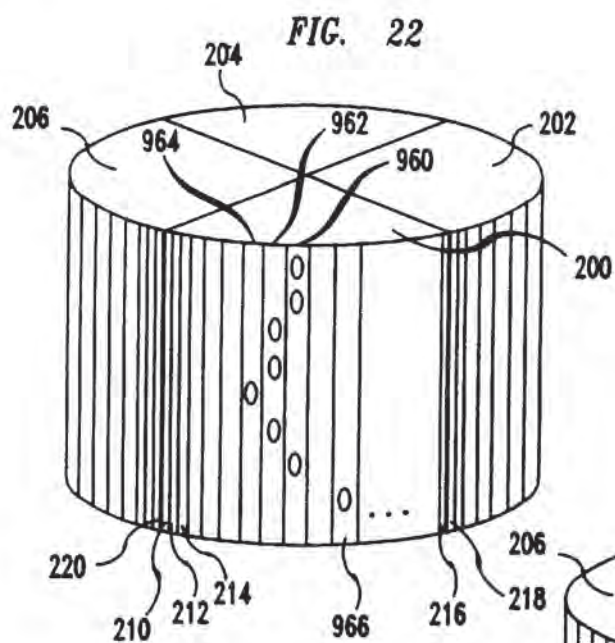
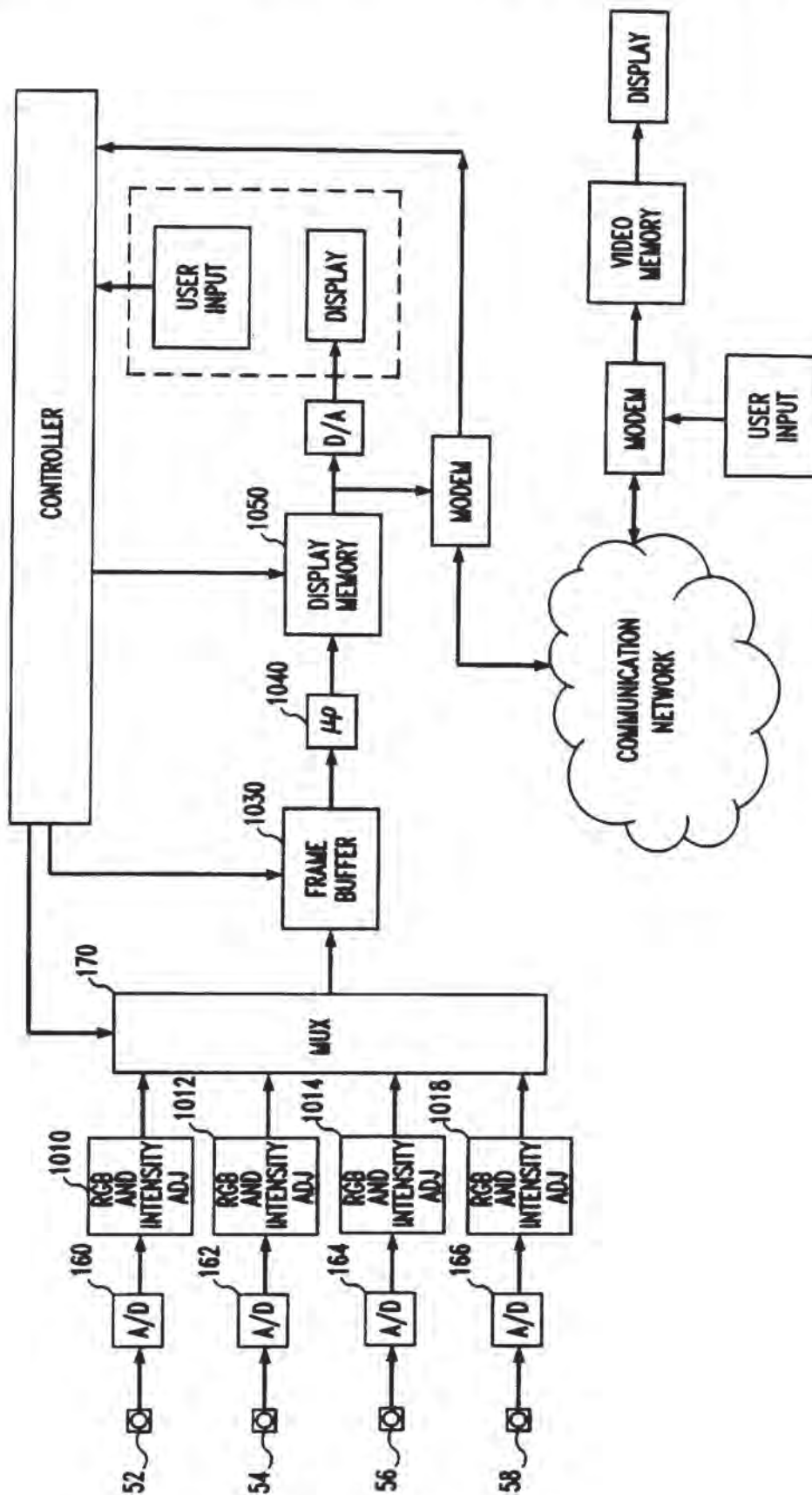


FIG. 25



PANORAMIC VIEWING SYSTEM WITH SUPPORT STAND

CROSS REFERENCE TO RELATED INVENTIONS

This application is related to the following commonly assigned US Patent Applications: "Panoramic Viewing Apparatus", Ser. No. 08/431,356 which issued as U.S. Pat. No. 5,745,305; "Method And System For Panoramic Viewing", filed Apr. 28, 1995, Ser. No. 08/43135; "High Resolution Viewing System", Ser. No. 08/497673, which issued as U.S. Pat. No. 5,793,527; "Panoramic Projection Apparatus", Ser. No. 08/497341, which issued as U.S. Pat. No. 5,539,483; "Spherical Viewing/Projection Apparatus", filed Nov. 30, 1995, Ser. No. 08/565501; "Panoramic Viewing System With Offset Virtual Optical Center", filed Oct. 7, 1997, Ser. No. 08/946443; commonly assigned and concurrently filed US Patent Application entitled "Compact High Resolution Panoramic Viewing System"; and commonly assigned and concurrently filed US Patent Application entitled "Stereo Panoramic Viewing System", filed Aug. 28, 1998, Ser. No. 09/141,867.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a viewing system; more particularly, a panoramic viewing system.

2. Description of the Related Art

In an effort to operate more efficiently, it is desirable to perform some tasks using telepresence. Telepresence refers to providing visual or other types of sensory information from a device at a remote site to a user that makes the user feel as if he/she is present at the remote site. For example, many businesses now hold meetings using telepresence. Telepresence is also useful for distance learning and remote viewing of events such as concerts and sporting events. A more realistic telepresence is provided to a user by providing the user with the capability to switch between views, and thereby mimic, for example, looking around a meeting room.

In the past, when several views were made available to a user, several cameras with different optical centers were used. Such a situation is illustrated in FIG. 1. FIG. 1 illustrates cameras 2, 4, 6, and 8 with optical centers 10, 12, 14, and 16, respectively. When the user decided to change views, he or she simply switched between cameras. In more sophisticated systems, when a user decided to change views, he or she was able to obtain a view from optical centers 10, 12, 14, or 16 as well as from additional optical centers 18, 20, 22, 24, or 26. Views associated with optical centers such as 18, 20, 22, 24, and 26 were obtained by using views from the two cameras nearest to the selected optical center. For example, a view from optical center 18 was obtained by using the views from cameras 2 and 4 and interpolating between the two views so as to simulate a view from optical center 18. Such procedures introduced irregularities into views. In addition, forming these interpolated views required a large amount of computational power and time, and thereby made this technique expensive and slow to respond to a user's commands. This computational overhead also limited the number of users that could simultaneously use the system.

SUMMARY OF THE INVENTION

One embodiment of the present invention provides an omnidirectional or panoramic viewer in which multiple

cameras effectively have a common optical center at least one of these cameras having its field of view redirected by a planar mirror. The field of view of each of the cameras is arranged to form a continuous 360 degree view of an area when taken as a whole. The user can sweep through 360 degrees of viewing, where each view has the same or nearly the same optical center, by simply using the output of one camera, more than one or the combination of cameras without requiring the computational overhead of interpolation used in the prior art. Such an arrangement may be used to enhance use of virtual meeting rooms by allowing a viewer to see the meeting room in a more natural format. This format corresponds closely to a person sitting in the actual meeting who simply turns his or her head to change the view at a particular time.

In another embodiment of the invention, the cameras are positioned so that they each views a different reflective surface of a solid or hollow polyhedron such as a solid or hollow pyramid. This results in each camera having a virtual optical center positioned within the pyramid. The cameras are positioned so that their virtual optical centers are offset from each other. The offsets produce narrow blind regions that remove image distortions received from the edges of the pyramid's reflective surfaces. A pyramid is supported by a post that passes through the vertex of the pyramid. Small cameras are then mounted to the post to provide a panoramic viewer with a mounting structure and a structure for supporting individual cameras.

In still another embodiment of the invention, a stereo panoramic view is provided through the use of multiple virtual optical centers. A reflective polyhedral element, such as a pyramid, redirects the field of view of each camera in a first set of cameras to form a group of substantially co-located virtual optical centers at a first location within the pyramid. The pyramid also redirects the field of view of each camera in a second set of cameras to form a group of substantially co-located virtual optical centers at a second location within the pyramid. Panoramic images from the first and second virtual optical centers provide a stereo panoramic view when one panoramic image is provided to a user's left eye and the other panoramic image is provided to the user's right eye.

In yet another embodiment of the present invention, polyhedrons such as pyramids having reflective surfaces are stacked base to base or nested within each other to produce a compact panoramic viewer. Using multiple reflective polyhedrons in such a manner permits using many cameras with the same or nearly the same virtual optical center. Using many cameras divides a large viewing area into many smaller areas where an individual camera views each smaller area. Since each camera views a smaller area, increased resolution is provided to the user. The pyramids are supported by a post that passes through their vertices. Cameras are then mounted to the post to provide a panoramic viewer with a mounting structure and a structure for supporting individual cameras.

In yet another embodiment of the present invention, the viewing device may include any type of image processing device. If the image processing device is a camera or other type of image capture device, a panoramic image is captured for the user, and if the image processing device is a projector or other type of image producing device, a panoramic image is produced for the user.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 illustrates a prior art multiple camera viewing system;

FIG. 2 illustrates a four camera omnidirectional or panoramic viewing system using a four-sided pyramid with reflective surfaces;

FIG. 3 illustrates how a reflective surface of the pyramid is used to provide each camera with a common optical center;

FIG. 4 illustrates the top view of the pyramid illustrating the camera positions;

FIG. 5 illustrates an eight-sided pyramid with reflective side surfaces;

FIG. 6 is a top view of the pyramid of FIG. 5;

FIG. 7 is a block diagram of a system to control data produced by the cameras;

FIG. 8 illustrates the association between the data received from the cameras and the view presented to a user;

FIG. 9 illustrates an addressing scheme for the memory of FIG. 7;

FIG. 10 is a block diagram of the controller of FIG. 7;

FIG. 11 illustrates the viewing system of FIG. 2 with a fifth camera;

FIG. 12 illustrates a top view of the pyramid of FIG. 2 with displaced virtual optical centers;

FIG. 13 illustrates the pyramid of FIG. 12 with shades positioned in blind regions;

FIG. 14 illustrates a panoramic viewer using pyramids stacked base to base;

FIG. 15 illustrates a panoramic viewer using nested pyramids;

FIG. 16 illustrates a spherical viewer using nested pyramids;

FIG. 17 illustrates a stand used to support a panoramic;

FIG. 18 illustrates the viewer of FIG. 14 with a support stand;

FIG. 19 illustrates the view of FIG. 15 with a support stand;

FIG. 20 illustrate two types of distortion;

FIG. 21 illustrates a calibration process;

FIG. 22 illustrates the association between data received from the cameras and the view presented to the user with distortion;

FIG. 23 illustrates how distorted image data is stored;

FIG. 24 illustrates how mapped image data is stored; and

FIG. 25 is a block diagram of a panoramic camera system where image mapping is used.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 2 illustrates a four camera system for providing a 360 degree view to a user, where the cameras each have a common or nearly common virtual optical center within the pyramid. Pyramid 40 has reflective sides 42, 44, 46, and 48 and may be a hollow, solid or truncated structure. In a preferred embodiment, each of the reflective sides forms a 45 degree angle with a plane parallel to base 50 and passing through the vertex of pyramid 40. Cameras 52, 54, 56, and 58 are associated with pyramid reflective surfaces 48, 42, 44, and 46, respectively. The cameras may be image gathering devices such as an optical scanner. As a result, camera 52 views a reflection from surface 48 to enable it to view objects in the direction of arrow 60. Camera 54 views a reflection from surface 42 to view objects in the direction of arrow 62. Camera 56 views a reflection from surface 44 to

view objects in the direction of arrow 64, and camera 58 views a reflection from surface 46 to view objects in the direction of arrow 66. Each camera has a 90 degree field of view; however, larger fields of view may be used and the overlapping portion of the images may be removed by deleting or combining the pixels associated with the overlapping views. The combination of the four cameras viewing reflections from their associated reflective surfaces on pyramid 40, produce a 360 degree view of the area surrounding pyramid 40. When the mirrors are at 45 degree with respect to the pyramid base, it is desirable to locate the optical center of each camera on a plane that is parallel to base 50 and intersects vertex 70 of pyramid 40. Each camera's optical center should also be located on a line that passes through vertex 70 and is perpendicular to the base line of the camera's associated reflective surface. For example, the optical center of camera 54 is located on line 72. Line 72 is perpendicular to base line 74 of reflective surface 42. Line 72 is in a plane that passes through vertex 70 and is parallel to base 50. Likewise, the optical center of camera 56 is positioned on line 76 which is perpendicular to baseline 78, the optical center of camera 58 is positioned on line 80 which is perpendicular to base line 82, and the optical center of camera 52 is positioned on base line 84 which is perpendicular to base line 86.

Each camera optical center is positioned on one of the above described lines at a distance X from vertex 70 and each camera has its optical axes or direction of view pointing perpendicular to base 50. (The distance X should be such that the reflective surface reflects as much of the camera's field of view as desired; however, the defects in the reflective surface become more visible when the camera is moved closer to the reflective surface.) This positioning of optical centers results in the cameras sharing a virtual optical center located at, or substantially at, position 90. Virtual optical center 90 is located a distance X from the vertex 70 on a line that passes through vertex 70 and is perpendicular to base 50.

Although a pyramid configuration has been discussed in this example, different planar mirror geometries may be used to redirect fields of view so that the cameras have virtual optical centers that are substantially co-located. For example, solid, hollow or partial polyhedrons may be used. Additionally, in the case of a pyramid configuration the base and vertex do not have to be physically present and can be thought of as conceptual aids such as a base plane or end and vertex point or end.

FIG. 3 illustrates another view of pyramid 40 where only camera 54 is shown for the sake of simplicity. Camera 54 is positioned on line 72 so as to have a virtual optical center at, or nearly at, position 90 within pyramid 40. If camera 54 has a 90 degree field of view in the direction perpendicular to base 50, and if the optical center of camera 54 is at a distance of X from vertex 70 along line 72, camera 54 has a 90 degree view in the direction of arrow 62. In similar fashion, cameras 56, 58, and 52 have 90 degree views in the direction of arrows 64, 66, and 60, respectively. This arrangement inexpensively produces a 360 degree field of view of an area because cameras with a 90 degree field of view have relatively inexpensive optics.

FIG. 4 is a top view of pyramid 40. FIG. 4 illustrates the placement of the optical center of camera 54 along line 72. Line 72 should be in a plane passing through vertex 70 and is parallel to base 50. The line should also be perpendicular to base line 74 of pyramid 40. The camera's optical center should be positioned a distance X, or a distance substantially equal to X, from vertex 70 along line 72. Point 100 is located

on base 50 at a position where a line from vertex 70 perpendicularly intersects base 50. In a similar fashion, the optical centers of cameras 56, 58 and 52 are positioned the distance X, or a distance substantially equal to X, along lines 76, 80 and 84, respectively.

FIG. 5 illustrates an eight-sided pyramid 120. Pyramid 120 has reflective surfaces 122 where each of surfaces 122 forms a 45 degree angle with a plane that passes through vertex 130 and is parallel to base 124. As with the four-sided pyramid of FIG. 2, each reflective surface of FIG. 5 may have a camera associated with it. Each camera's optical center is positioned on a line that is in a plane that passes through vertex 130 and is parallel to base 124. The line is perpendicular to base line 132 of the reflective surface associated with the camera to be positioned. Using an eight-sided pyramid offers the advantage of using cameras with only a 45 degree horizontal field of view to obtain a 360 degree view. Cameras with only a 45 degree field of view have inexpensive optics and enable a 360 degree view to be constructed using relatively inexpensive components.

FIG. 6 is a top view of pyramid 120. As discussed with regard to FIG. 5, each camera's optical center is positioned along a line 134 which is in a plane that passes through vertex 130 and is parallel to base 124. The optical centers are positioned a distance X, or a distance substantially equal to X, along line 134 which is perpendicular to the appropriate base line 132. Point 140 is on base 124 at the point of intersection between base 124 and a line that passes through vertex 130 and is perpendicular to base 124.

Polyhedrons or pyramids having more or less reflective sides may be used. The advantage of using pyramids having a large number of sides is that cameras with moderate to small fields of view may be used. Cameras with moderate fields of view have relatively inexpensive optics. The number of sides used in a pyramid is somewhat limited by the cost of providing a large number of cameras. A 360 degree view of a scene may be provided using a pyramid having three reflective sides. It may be expensive to use only a three-sided pyramid in order to provide a 360 degree field of view. This embodiment of the invention uses three cameras each with a 120 degree field of view, and cameras with such a wide field of view use relatively expensive optical components.

In applications where a full 360 degree view is not desired, it is possible to build a viewer that does not have a camera associated with each reflective surface of the pyramid. In addition to eliminating an unnecessary camera, it is also possible to eliminate an unnecessary pyramid polyhedron surface by using reflective elements that are partial pyramids or partial polyhedrons.

Although a pyramid configuration has been discussed in this example, different planar mirror geometries may be used to redirect fields of view so that the cameras have virtual optical centers that are substantially co-located. For example, solid, hollow or partial polyhedrons may be used. Additionally, in the case of a pyramid configuration the base and vertex do not have to be physically present and can be thought of as conceptual aids such as a base plane or end and vertex point or end.

FIG. 7 illustrates a block diagram of a system for controlling data produced by the cameras of a viewing device such as the viewing device described in FIGS. 2 through 4. Cameras 52, 54, 56 and 58 obtain a 360 degree view of an area via their associated reflective surfaces of pyramid 40. The image signal or output signal of cameras 52, 54, 56 and 58 are passed through analog to digital converters (A/D)

160, 162, 164, and 166, respectively. The output of the cameras can be thought of as a stream of pixels and the output of the A/Ds can be thought of as data representative of the pixels from the cameras. The output of the A/Ds are passed through mux 170. Mux 170 allows the pixel data from each of the A/Ds to reach memory 172. Controller 174 cycles the select lines of mux 170 so that the outputs of all of the A/Ds are stored in memory 172. Mux 170 is switched at a rate that is four times the pixel rate of the cameras. If more or less cameras are used, the rate at which mux 170 is switched will be increased or slowed accordingly. It is also possible to eliminate mux 170 and to store the output of each A/D in a separate memory. Controller 174 is implemented using a microprocessor which provides control signals to counters that control the switching of mux 170 and counters used to provide addressing to memory 172. The control signals to the counters include reset, enable and a starting offset.

As a result of the pixel information being passed to memory 172, memory 172 contains a 360 degree view of a scene. Pixel information stored in memory 172 is passed through digital to analog converter (D/A) 176 and to video display 178. The actual portion of memory 172 that is passed to video display 178 via D/A 176 is controlled via user input device 180. User input device 180 may be a common device such as a mouse, joystick, or keyboard. The user may simply lean a joystick to the right to shift his view to the right, lean the joystick to the left to shift the view to the left, or leave the joystick in the center to keep the view unchanged. Based on the input from user device 180, controller 174 varies offsets and starting addresses that are used to provide addressing to memory 172.

FIG. 8 illustrates the relationship between the data provided by the cameras and the view available to the user. Since the cameras share a virtual optical center, the view can be thought of as a cylindrical view. Sector 200 can be thought of as representing the information provided by camera 52, sector 202 can be thought of as representing the information provided by camera 54, sector 204 can be thought of as representing the information provided by camera 56, and sector 206 can be thought of as representing the information provided by camera 58. The surface of the cylinder in each sector can be thought of as a collection of columns, where each column is composed of pixels. For example, sector 200 can be thought of as a collection of columns including columns 210, 212, 214, and 216. Likewise, the output produced by camera 54 can be thought of as a collection of columns which include column 218 in sector 202 and the output of camera 58 can include columns such as column 220 in sector 206.

FIG. 9 illustrates how memory 172 is divided to provide easy access to different views based on signals from user input device 180. Sections 230, 232, 234, and 236 correspond to sectors 206, 200, 202, and 204, respectively. Each of sections 230, 232, 234, and 236 can be thought of as a block within memory 172. The blocks in memory 172 are broken into columns of sequential addresses. The first column of memory segment 230 corresponds to the first column of pixels of sector 206. The number of memory positions associated with a column should be at least sufficient to have one location for each pixel in a particular column. For example, if a column of pixels from FIG. 8 includes 1000 pixels, each column associated with the memory segments of FIG. 9 should have at least 1000 locations. The number of columns associated with a particular memory segment should be at least equal to the number of columns associated with a particular section of the cylinder of FIG. 8.

If a camera scans in a horizontal direction, sequential pixels are written in adjacent columns, but possibly different rows, of a particular memory segment by simply changing an offset to a counter generated address. The overall write address is generated by adding the offset to the counter's output. This offset is changed at the rate in which the horizontally scanned pixels are received. After a horizontal scan is completed, the counter is incremented and once again the offsets are changed at the horizontal scan rate. As a result, when addressing a particular segment of memory during a write cycle, the columns are addressed by changing the offset at the horizontal pixel scan rate, and incrementing the counter at the vertical scan rate. This type of addressing scheme is used for accessing columns within each memory segment. When addressing different memory segments during a write cycle, a write segment offset is added to the sum of the counter output and the column offset. The write segment offset permits addressing memory segments 230, 232, 234, and 236. The segment offset is changed at the same rate as mux 170 is switched.

Pixel data is read from memory 172 in a similar fashion. The sum of a counter output and two sets of offsets are used to generate a read address. Once an initial starting column has been picked, the read address is generated by switching a read column offset at a rate that is equal to the horizontal scan rate of a video display. After reading one horizontal scans worth of data, the read counter is incremented and the read column offsets are changed at a rate equal to the horizontal scan rate of the display. As a result, the offset addresses are changing at the display's horizontal display rate and the counter is incremented at a rate equal to the vertical scan rate of a display. It is possible to read data out at a rate faster or slower than required by the video display; however, if read out faster, a buffer memory should be used, if read out slower the video display may appear choppy to the viewer.

It should be noted that the cylindrical arrangement of pixels of FIG. 8 is typically displayed on a flat or nearly flat display. As a result, the image may be displayed by compensating for converting between a cylindrical surface and a flat surface. This may be carried out using a simple conversion algorithm within a common digital signal processing integrated circuit. Methods for these types of conversions are well known in the art and can be found in "A Guided Tour of Computer Vision, Vishvjit S. Nalwa, Addison-Wesley Publishing Co., Reading, Mass., 1993." It is also possible to carry out the conversion using a very high resolution display.

It should be noted that if the view selected by a user corresponds exactly to the view of a particular camera, such as camera 52, columns 240-248 are read from memory 170. Column 240 is the first column in segment 232 and column 248 is the last column in segment 232. If the user decides to move the view in a counter-clockwise direction, the start column will shift to the right so that the read operation begins at column 246 and ends at column 250. It should be noted that column 246 is the second column associated with memory segment 232 which has the pixel data from camera 52, and that column 250 is the first column of pixel data associated with camera 56. As the user shifts the view, the starting column shifts in relationship to the user's commands. For example, if the user indicates that the view should shift in a counter-clockwise direction, the start column of FIG. 9 moves to the right, similarly, if the viewer indicates that the view should shift in a clockwise direction, the start column shifts to the left. As before, columns are addressed by using offsets, if the offsets involve moving

between memory segments, a read segment offset is added to the sum of the column offset and counter output.

FIG. 10 illustrates a block diagram of controller 174. Controller 174 includes microprocessor 270 and memory 272. Memory 272 includes RAM and ROM. Processor 270 receives commands on line 274 from user input device 180. Microprocessor 270 controls start, stop and reset of counter 276. Counter 276 controls the select lines of mux 170. Counter 276 counts at a rate that is four times the horizontal scan rate of the cameras. Write address generator 278 provides write addressing for memory 172. Write address generator 278 includes a counter, register for storing offsets and adder for adding the offsets and counter output. Microprocessor 270 controls the offset selection and the counters used by write address generator 278. The write addresses are formed as described with regard to FIG. 9. Read address generator 280 provides read addresses to memory 172. Read address generator 280 includes a counter, register for storing offsets and adder for adding the offsets and counter output. As with write address generator 278, microprocessor 270 controls the offset selection and the counters of read address generator 280. Microprocessor 270 also controls the starting column used by the counters based on inputs provided on line 274 from user input 180.

The write and read addresses are provided to memory 172 separately if memory 172 is implemented using a two port memory. If memory 172 is implemented with a single port memory, the write and read addresses are multiplexed to memory 172.

FIG. 11 illustrates the viewing system of FIG. 2 with a fifth camera. Camera or image gathering device 400 is located in pyramid 40 with the optical center of camera 400 located at, or nearly at, virtual optical center 90. Camera 400 views objects in the direction of arrow 410. The resulting view coupled with the views of the remaining four cameras, provides a nearly spherical view. If the cameras of FIG. 11 are replaced with image producing devices, the nearly spherical viewing system becomes a nearly spherical projection system. It should be noted, that a camera or projection device, may be placed at the virtual optical center of viewing/projection devices having pyramids with three, four or more sides. It should also be noted that base edges 420 of the reflective surfaces should be beveled to avoid undesirable obstruction of camera 400's field of view. It is also possible to avoid undesirable image artifacts from base edges 420 by moving camera or image processing device 400. Device 400 should be moved so that device 400's optical center is positioned away from virtual optical center 90 in the direction of arrow 410. Device 400's optical center should be positioned so that the device's field of view does not include edges 420.

FIG. 12 illustrates a top view of the pyramid of FIG. 2. In reference to FIG. 2, camera 52, 54, 56, and 58 have been moved upward in the direction of base 50. As a result, virtual optical centers 500, 502, 504 and 506, which correspond to cameras 52, 54, 56 and 58, respectively, are moved away from virtual optical center 90. It is desirable to move the virtual optical centers so that camera 52 captures an image between lines 508 and 510 that are unaffected by an edge of the pyramid, camera 54 captures an image between lines 512 and 514 that are unaffected by an edge of the pyramid, camera 56 captures an image between lines 516 and 518 that are unaffected by an edge of the pyramid, and camera 58 captures an image between lines 520 and 522 that are unaffected by an edge of the pyramid. This results in the cameras not capturing images distorted by edges of the pyramid from narrow planar shaped regions. In particular,

planar regions 524, 526, 528, and 530 are not used and form blind regions. This offers the advantage of removing image regions that are distorted by the edges of the reflective pyramid. Eliminating these portions of the fields of view alleviates the need to provide image processing that compensates for image artifacts at the edges. It is desirable to keep virtual optical centers 500, 502, 504, and 506 closely clustered so that planes 524, 526, 528, and 530 are only as thin as necessary to avoid edge artifacts. By maintaining such thin planes, the need to process the images at their common boundaries is removed while minimizing the noticeable effect seen by a user.

FIG. 13 illustrates the pyramid of FIG. 12 with shades 560, 562, 564, and 566 positioned in planar regions 524, 526, 528, and 530, respectively. The shades reduce the amount of unwanted light that enters the cameras. Similar shades may be placed in blind regions between device 400 and one or more of the other image processing devices. It is also possible to place a shade on base 50 with the edges of the shade extending beyond the edges of the base to reduce the amount of unwanted light that enters cameras 52, 54, 56, and 58 from sources behind base 50.

FIG. 14 illustrates reflective pyramids 602 and 604 arranged in a base-to-base configuration. The bases may be in contact with each other or spaced apart. Reflected pyramids 602 and 604 each have four reflective side facets. Pyramid 602 has reflective side facets 608, 610, 612, and 614. Reflective pyramid 604 has reflective sides 616, 618, 620, and 622. Pyramid 602 includes vertex 624 and pyramid 604 includes vertex 626. Vertices 624 and 626 are on a line 628 that is perpendicular to the base of each pyramid. Each pyramid has four image processing devices such as cameras with a field of view being redirected by a reflective surface. With regard to pyramid 602, a camera with an optical center positioned at point 630 has a field of view in the direction of arrow 632 where that field of view is redirected by reflective surface 608. A second camera with an optical center at point 634 has a field of view in the direction of arrow 636 which is redirected by reflective surface 610. A third camera with an optical center at point 638 has a field of view in the direction of arrow 640 which is redirected by reflective surface 612. A fourth camera with an optical center at point 642 has a field of view in the direction of arrow 644 which is redirected by reflective surface 614. Regarding reflective pyramid 604, a first camera with an optical center at point 646 has a field of view in the direction of arrow 648 which is redirected by reflective surface 616. A second camera with an optical center at point 650 has a field of view in the direction of arrow 652 which is redirected by surface 618. A third camera with an optical center at point 654 has a field of view in the direction of arrow 656 which is redirected by reflective surface 620. A fourth camera with an optical center at point 658 has a field of view in the direction of arrow 660 which is redirected by reflective surface 622. The cameras associated with each of the pyramids are positioned in a way similar to how the cameras were positioned with regard to FIGS. 2, 3, 4, 11, and 12 so that each set of four cameras shares a common virtual optical center or have closely clustered virtual optical centers within their associated pyramid. Each set of cameras may also have offset virtual optical centers within their associated pyramid. The cameras may be positioned so that the cameras associated with each pyramid share a common virtual optical center along line 628 where the bases of the two pyramids meet. It is also possible to position the cameras so that their offset virtual optical center are clustered about a point on line 628 where the bases of the two pyramids meet.

The structure of FIG. 14 increases the vertical field of view as compared to the viewers discussed with regard to FIGS. 2, 3 and 4. The viewer of FIG. 14 increases the vertical field of view by using two cameras rather than one camera for the same or nearly the same horizontal field of view. It should be noted that a projector may be constructed by replacing the cameras with image producing devices. It should also be noted that reflective pyramids 602 and 604 may be rotationally misaligned with respect to each other. This misaligned relationship is obtained by rotating one or both of the pyramids about an axis that passes through the vertices of both pyramids. For example, the axis may be co-linear with line 628. As a result of this rotation, the side edges of the reflective side facets of pyramid 602 will not align with the side edges of the reflective side facets of pyramid 604.

Although a pyramid configuration has been discussed in this example, different planar mirror geometries may be used to redirect fields of view so that the cameras have virtual optical centers that are substantially co-located. For example, solid, hollow or partial polyhedrons may be used. Additionally, in the case of a pyramid configuration the base and vertex do not have to be physically present and can be thought of as conceptual aids such as a base plane or end and vertex point or end.

FIG. 15 illustrates two reflective pyramids. Reflective pyramid 702 is nested within reflective pyramid 704. It should be noted that more than two reflective pyramids may be nested. For example, another reflective pyramid may be nested within reflective pyramid 702 and yet another reflective pyramid may be nested within the pyramid that is nested within pyramid 702. Vertex 706 of pyramid 702 and vertex 708 of pyramid 704 are on a line 710 which is perpendicular to the bases of both pyramids. Once again, each pyramid includes four image processing devices such as cameras each with a field of view that is redirected by a reflective surface of their associated pyramid. Pyramid 702 includes reflective side facets 712, 714, 716, and 718. Reflective pyramid 704 includes reflective side facets 720, 722, 724, and 726. Four cameras are positioned so that their field of view is redirected by the reflective surfaces of pyramid 702. A first camera with an optical center at point 730 and a field of view in direction of arrow 732 has its field of view redirected by reflective surface 712. A second camera with an optical center at point 734 and a field of view in the direction of arrow 736 has its field of view redirected by reflective surface 714. A third camera with an optical center at point 738 and a field of view in the direction of arrow 740 has its field of view redirected by reflective surface 716. A fourth camera with an optical center at point 742 and a field of view in the direction of arrow 744 has its field of view redirected by reflective surface 718. It should be noted that pyramid 702 and its associated cameras are positioned so that the field of view of the cameras is not obstructed by pyramid 704. This is accomplished by allowing pyramid 702 to extend beyond the base of pyramid 704. Regarding pyramid 704, a first camera with an optical center at point 750 and a field of view in the direction of arrow 752 has its field of view redirected by reflective surface 720. A second camera with an optical center at point 754 and a field of view in the direction of arrow 756 has its field of view redirected by reflective surface 722. A third camera with an optical center at point 758 and a field of view in the direction of arrow 760 has its field of view redirected by reflective surface 724. A fourth camera with an optical center at point 762 and a field of view in the direction of arrow 764 has its field of view redirected by reflective surface 726. The

cameras associated with each of the pyramids are positioned in accordance with the positioning illustrated with FIGS. 2, 3, 4, 11, and 12 so that the eight cameras share a virtual optical center at position 770 or have closely clustered virtual optical centers within pyramid 702. Each set of cameras may also have offset virtual optical centers within pyramid 702.

The panoramic viewer of FIG. 15 can be provided with a ninth camera having an optical center at point 770 and a field of view in the direction of arrow 772 to provide a viewer with a partially-spherical view. The camera having an optical center at position 770 may use a wide-angle lens to provide a broader view.

FIG. 16 illustrates the partially-spherical viewer of FIG. 15 with an additional camera having an optical center at point 780 and a field of view in the direction of arrow 782 where that field of view is redirected by planar mirror 784. It should be noted that optical center 780 is on line 710 which passes through the vertices of pyramid 702 and 704 as well as virtual optical center 770. It should also be noted that point 780 is placed a distance away from planar mirror 784 that is equal or nearly equal to the distance between planar mirror 784 and virtual optical center 770. By placing a camera with an optical center at point 780 and having the field of view redirected by planar mirror 784, the partially-spherical viewer of FIG. 15 becomes a spherical viewer. In order to increase the field of view of the camera positioned with an optical center at point 780, the camera may be provided with a wide-angle lens. It should also be noted that planar mirror 784 may be replaced with a curved mirror to provide a wider field of view for the camera positioned at point 780 and minimize the need for a wide-angle lens.

Although a pyramid configuration has been discussed in this example, different planar mirror geometries may be used to redirect fields of view so that the cameras have virtual optical centers that are substantially co-located. For example, solid, hollow or partial polyhedrons may be used. Additionally, in the case of a pyramid configuration the base and vertex do not have to be physically present and can be thought of as conceptual aids such as a base plane or end and vertex point or end.

Regarding FIGS. 15 and 16, it should be noted that a projector may be constructed by replacing the cameras with image producing devices. It should also be noted that reflective pyramids 702 and 704 may be rotationally misaligned with respect to each other. This misaligned relationship is obtained by rotating one or both of the pyramids about an axis that passes through the vertices of both pyramids. For example, the axis may be co-linear with line 710. As a result of this rotation, the side edges of the reflective side facets of pyramid 702 will not align with the side edges of the reflective side facets of pyramid 704.

FIG. 17 illustrates a stand used to support a panoramic viewer. Reflective pyramid 800 is mounted to stand or post 802 using a support member such as hollow tube 804. The pyramid is secured to hollow tube 804 at vertex end 806. The hollow tube is secured to stand 802 by angle brackets 808. Hollow tube 804 extends beyond vertex end 806 so that cameras 810 may be supported by tube 804. The cameras are mounted to tube 804 by strap or belt 812 which presses cameras 810 against spacer 814. The pressure provided by clamp or strap 812 provides friction between camera 810, spacer 814, and the outer surface of tube 804 and thereby mounts cameras 810 to tube 804 in a secure fashion. It is also possible to provide a second strap and associated spacers at end-section 816 of cameras 810. Video and power connec-

tions to cameras 810 are provided by cables 818 which are fed through hollow tube 804 and out through space 820 which is between post 802 and the base of pyramid 800. It should be noted that hollow tube 804 may be replaced with a solid support member; however, a hollow support member provides a convenient path for routing cables. Feeding the cables through tube 804 prevents the cables from entering the field of view of cameras 810. Rubber stands or feet 824 are provided at the base end of pyramid 800. These stands may be used in place of post 802 to provide flexibility in application where the user does not want to use post 802.

It is also possible to invert the viewer of FIG. 17 so that the viewer is supported by end 830 of tube 804. In this configuration cables 818 will simply be passed out through an opening at end 830 of tube 804. In this configuration tube 804 is mounted to post 802 at end 830 using angle brackets similar to angle brackets 808. It is also possible to mount end 830 to any convenient structure to support the panoramic viewer.

The stand of FIG. 17 is applicable to the viewer of FIGS. 14, 15, and 16. As discussed with regard to FIG. 17, the viewer is mounted to a hollow tube passing through the vertices or vertex ends of both pyramids. FIG. 18 illustrates the viewer of FIG. 14 mounted to the stand of FIG. 17 and FIG. 19 illustrates the viewer of FIG. 15 mounted to the stand of FIG. 17.

Calibration

A higher quality image may be produced by calibrating the camera system. Calibration may be used to determine image mapping functions (which may be implemented as look up tables) that compensate for different types of image distortion. For example, the mapping functions may be used to correct barrel distortion which is a distortion introduced by a wide-angle lens. Mapping functions may also be used to correct other types of distortions such as a rotational distortion resulting from misaligned charged coupled devices within the cameras. FIG. 20 illustrates a combination of barrel distortion and rotational distortion, where the distortion results in rectangular object 900 appearing as distorted image 902. Distorted image 902 is rotated with respect to undistorted object 900 and a barrel distortion is seen where edges 904 and 906 of rectangular object 900 appear as edges 908 and 910 of image 902, and where edges 912 and 914 appear as edges 916 and 918, respectively. This distortion may be corrected using mapping functions that are determined by calibrating the camera system.

FIG. 21 illustrates a process for calibrating the camera system. A vertical column of equally spaced elliptical dots 930 is placed in a fixed position. The dots are white on a black background where the major axis of the elliptical dot is in the vertical direction. Panoramic camera 940 is then rotated in small discrete steps about an axis 942 passing through the virtual optical center of the panoramic camera. At each step, the distorted image of the column of elliptical dots is viewed and a mapping function for that data is determined to remove the distortion. This function maps the image such that the distorted image of each vertical column of equally spaced dots is a vertical column of equally spaced dots in the mapped image. Note that although the images of the white dots have black gaps between them, the mapping function is computed to apply to every image pixel (including the pixels between the white dots) through interpolation. An image mapping function is determined at each of the discrete steps as the camera is rotated, the union of these mapping functions is combinable into a 2-D to 2-D mapping that ensures not only that each vertical column of equally spaced dots appears as a vertical column of equally

spaced dots in the image, but also that these columns are spaced horizontally in proportion to the angular rotation between their image acquisitions, the latter providing a cylindrical (rather than flat) image of the scene.

FIGS. 22 and 23 illustrate how the data representative of the vertical column of elliptical dots is represented as a result of distortion. FIG. 22 is similar to FIG. 8 in that it illustrates the relationship between the data provided by the cameras and the view available to the user. It should be noted that the vertical column of dots is not in a single column of FIG. 22 as a result of the distortion. The distortion has caused the dots to occupy columns 960, 962, 964 and 966, rather than just a single column. FIG. 23 is similar to FIG. 9 in that it illustrates how image data is stored. When the distorted image data is stored in memory as represented in FIG. 23, the data representative of the dots also occupies several columns where columns 980, 982, 984 and 986 correspond to the columns 960, 962, 964 and 966 of FIG. 22, respectively. The image mapping function determined during the calibration phase is used to correct for this distortion when the data is read from the memory represented in FIG. 23. The corrected or undistorted image data may then be displayed to the user or written to a memory used to store data representative of the undistorted image. FIG. 24 illustrates the relationship between the data read from the memory of FIG. 23 and the undistorted view made available to a user. For example, the mapping function associated with column 1000 specifies that when reading data for use in the uppermost portion of column 1000, data is read from column 980 and when reading data for use in the portion of column 1000 just below, data is read from column 982. The mapping function also specifies that when reading data for use in the middle portion of column 1000, data is read from column 984. Moving further down column 1000, data is then read from column 982, then column 980, and eventually from column 986 when data for use at the bottom of column 1000 is retrieved. As a result of reading data, as specified by the mapping function, the column of data will appear vertical to a user viewing a display. FIG. 24 illustrates that the data retrieved from the memory of FIG. 23 now appears as a vertical column where the distortion is no longer evident. A similar mapping function, as determined during calibration, is used for each column of FIG. 24 to produce an undistorted image for display. It should be noted that multiple discrete rotational steps used to calibrate the panoramic camera could be substituted by a group of several columns illustrated in FIG. 24.

Color and intensity calibration may also be carried out using a procedure similar to the procedure illustrated in FIG. 21. In this case, column 930 of elliptical dots is replaced by a known color pattern. The panoramic camera is then rotated so that each camera captures an image of the color pattern. Several color patterns (such as various shades of red, green, blue, and gray) could be used one by one. Then on a pixel-by-pixel basis, the data from each camera is adjusted to correct any red, green, or blue distortion so that the produced image has a color pattern that closely matches the calibration color pattern. Additionally, the intensity of each pixel from each camera is adjusted so that there is relatively uniform intensity and color within a single camera's image and between the images of the multiple cameras when viewing a scene with constant color and brightness. As discussed with regard to the mapping function, the pixel-by-pixel adjustment may be stored in a table. A less precise, but simpler method of color and intensity calculation may be used. This method simply involves manually adjusting the color and intensity controls of each camera to get correct

color and intensity when viewing a scene with a particular color and intensity. It should be noted that by using this method, all of the pixels of a particular camera receive the same adjustments.

FIG. 25 illustrates a panoramic camera system where calibration based image mapping correction is used. FIG. 25 is similar to FIG. 7; however, it should be noted that a frame buffer memory and an additional microprocessor have been included. Cameras 52, 54, 56, and 58 gather image data and then pass the data to analog-to-digital converters 160, 162, 164, and 166, respectively. The output of the analog-to-digital converters are then passed through red, green, blue, and intensity adjustment units 1010, 1012, 1014, and 1018. It is possible to place these units before the analog/digital converters, if the adjustment units are analog units. Additionally, it is also possible to use cameras that have the adjustment units built into each camera. In any case, the adjustment units are programmed or set to adjust the color and intensity as determined by the calculation procedures. Each of these units adjust the red, green, and blue levels and the overall levels of the signals from the analog-to-digital converter. It should be noted that if cameras 52 through 58 are color cameras, analog-to-digital converters 160 to 166 typically receive three signals and output three signals, where each pair of input and output signals corresponds to one of the colors red, green, and blue. Units 1010 through 1016 simply adjust the relative amplitudes of the red, green, and blue signals in accordance with the settings determined during the calibration procedure. Each of units 1010 through 1018 also adjust the overall amplitude of the red, green, and blue signals in accordance with the overall intensity calibration settings. The outputs of the red, green, and blue intensity adjustments are then passed through a multiplexer as discussed in FIG. 7, and are passed to frame buffer memory 1030. It is also possible to replace frame buffer 1030 with an individual frame buffer for each of red, green, blue and intensity units 1010, 1012, 1014, and 1018. The outputs of each of the individual frame buffer may then be passed to microprocessor 1030 via multiplexer 170.

Frame buffer memory 1030 is operated in a fashion similar to memory 172 of FIG. 7 and stores the data representing the distorted images as was discussed in reference to FIG. 23. Microprocessor 1040 then reads the data from frame buffer memory 1030 using the mapping functions determined during the calibration procedure and then writes the data into display memory 1050. Recalling the discussion associated with FIG. 24, the data representing undistorted images is then stored in memory 1050 for retrieval by the users. The users can retrieve the data as is discussed in reference to FIG. 7 where the data read out is determined based on a user's input. It is also possible for the entire contents of display memory to be made available to each user. The data may be communicated to each user through a communication network such as a telephone network or a data network, or it may be directly communicated to the user via a dedicated wired or wireless communication path. The user then may use a digital-to-analog converter to convert the data into an analog format that may be displayed for the user or the user may use the digital data directly and forego the use of a digital-to-analog converter.

The invention claimed is:

1. A panoramic viewing apparatus, comprising:

- a plurality of image processing devices, each having an optical center and a field of view;
- a reflective element being at least partially polyhedral having a plurality of reflective facets facing in different directions, each of at least two of the plurality of

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reflective facets redirecting a field of view of one of the plurality of image processing devices to create a plurality of virtual optical centers; and

a support member intersecting an inner volume of the reflective element, the reflective element being secured to the support member and the plurality of image processing devices being secured to the support member.

2. The panoramic viewing apparatus of claim 1, wherein the plurality of image processing devices are secured to a portion of the support member extending out from the reflective element.

3. The panoramic viewing apparatus of claim 1, wherein the support member is hollow.

4. A panoramic viewing apparatus, comprising:

- a plurality of first image processing devices, each having an optical center and a field of view;
- a plurality of second image processing devices, each having an optical center and a field of view;
- a first and a second reflective element each being at least partially polyhedral arranged adjacent to each other, the first reflective element having a plurality of first reflective facets facing in different directions, each of at least two of the plurality of first reflective facets redirecting a field of view of one of the plurality of first image processing devices to create a plurality of first virtual optical centers, and the second reflective element having a plurality of second reflective facets facing in different directions, each of at least two of the plurality of second reflective facets redirecting a field of view of one of the plurality of second image processing devices to create a plurality of second virtual optical centers; and
- a support member intersecting an inner volume of at least one reflective element, at least one of the reflective elements being secured to the support member and at least one of the plurality of first or second image processing devices being secured to the support member.

5. The panoramic viewing apparatus of claim 4, wherein the plurality of first image processing devices are secured to a first portion of the support member extending out from the first reflective element, and the plurality of second image processing devices are secured to a second portion of the support member extending out from the second reflective element.

6. The panoramic viewing apparatus of claim 4, wherein the support member is hollow.

7. A panoramic viewing apparatus, comprising:

- a plurality of first image processing devices, each having an optical center and a field of view;
- a plurality of second image processing devices, each having an optical center and a field of view;
- a first reflective element being at least partially polyhedral;
- a second reflective element being at least partially polyhedral with at least a portion of the second reflective element being positioned within the first reflective element, the first reflective element having a plurality of first reflective facets facing in different directions, each of at least two of the plurality of first reflective facets redirecting a field of view of one of the plurality of first image processing devices to create a plurality of first virtual optical centers, and the second reflective element having a plurality of second reflective facets facing in different directions, each of at least two of the

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plurality of second reflective facets redirecting a field of view of one of the plurality of second image processing devices to create a plurality of second virtual optical centers; and

a support member intersecting an inner volume of at least one reflective element, at least one of the reflective elements being secured to the support member and at least one of the plurality of first or second image processing devices being secured to the support member.

8. The panoramic viewing apparatus of claim 7, wherein the plurality of first image processing devices are secured to a first portion of the support member extending out from the first reflective element, and the plurality of second image processing devices are secured to a second portion of the support member extending out from the reflective element.

9. The panoramic viewing apparatus of claim 7, wherein the support member is hollow.

10. A panoramic viewing apparatus, comprising:

- plurality of image processing devices, each having an optical center and a field of view;
- a pyramid shaped element having a plurality of reflective side facets facing in different directions, each of at least two of the plurality of reflective side facets redirecting a field of view of one of the plurality of image processing devices to create a plurality of virtual optical centers; and
- a support member intersecting an inner volume of the pyramid shaped element, the pyramid shaped element being secured to the support member and the plurality of image processing devices being secured to the support member.

11. The panoramic viewing apparatus of claim 10, wherein the plurality of image processing devices are secured to a portion of the support member extending out from the pyramid shaped element.

12. The panoramic viewing apparatus of claim 10, wherein the support member is hollow.

13. A panoramic viewing apparatus, comprising:

- a plurality of first image processing devices, each having an optical center and a field of view;
- a plurality of second image processing devices, each having an optical center and a field of view;
- a first and a second pyramid shaped element arranged base end to base end, the first pyramid shaped element having a plurality of first reflective side facets facing in different directions, each of at least two of the plurality of first reflective side facets redirecting a field of view of one of the plurality of first image processing devices to create a plurality of first virtual optical centers, and the second pyramid shaped element having a plurality of second reflective side facets facing in different directions, each of at least two of the plurality of second reflective side facets redirecting a field of view of one of the plurality of second image processing devices to create a plurality of second virtual optical centers; and
- a support member intersecting an inner volume of at least one of the pyramid shaped elements, at least one of the pyramid shaped elements being secured to the support member and at least one of the plurality of first or second image processing devices being secured to the support member.

14. The panoramic viewing apparatus of claim 13, wherein the plurality of first image processing devices are secured to a first portion of the support member extending

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out from the first pyramid shaped element, and the plurality of second image processing devices are secured to a second portion of the support member extending out from the second pyramid shaped element.

15. The panoramic viewing apparatus of claim 13, §
wherein the support member is hollow.

16. A panoramic viewing apparatus, comprising:

plurality of first image processing devices, each having an optical center and a field of view;

a plurality of second image processing devices, each 10
having an optical center and a field of view;

a first pyramid shaped element having a first vertex end and a first base end;

a second pyramid shaped element having a second vertex 15
end and a second base end with at least a portion of the second pyramid shaped element being positioned within the first pyramid shaped element so that the first and second vertex ends point in the same direction, the first pyramid shaped element having a plurality of first 20
reflective side facets facing in different directions, each of at least two of the plurality of first reflective side facets redirecting a field of view of one of the plurality of first image processing devices to create a plurality of

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first virtual optical centers, and the second pyramid shaped element having a plurality of second reflective side facets facing in different directions, each of at least two of the plurality of second reflective side facets redirecting a field of view of one of the plurality of second image processing devices to create a plurality of second virtual optical centers; and

a support member intersecting an inner volume of at least one of the pyramid shaped elements, at least one of the pyramid shaped element being secured to the support member and at least one of the plurality of first or second image processing devices being secured to the support member.

17. The panoramic viewing apparatus of claim 16, wherein the plurality of first image processing devices are secured to a first portion of the support member extending out from the first pyramid shaped element, and the plurality of second image processing devices are secured to a second portion of the support member extending out from the second pyramid shaped element.

18. The panoramic viewing apparatus of claim 16, wherein the support member is hollow.

* * * * *

EXHIBIT C:

Photographs of the RoundTable Camera Head, Assembled & Disassembled

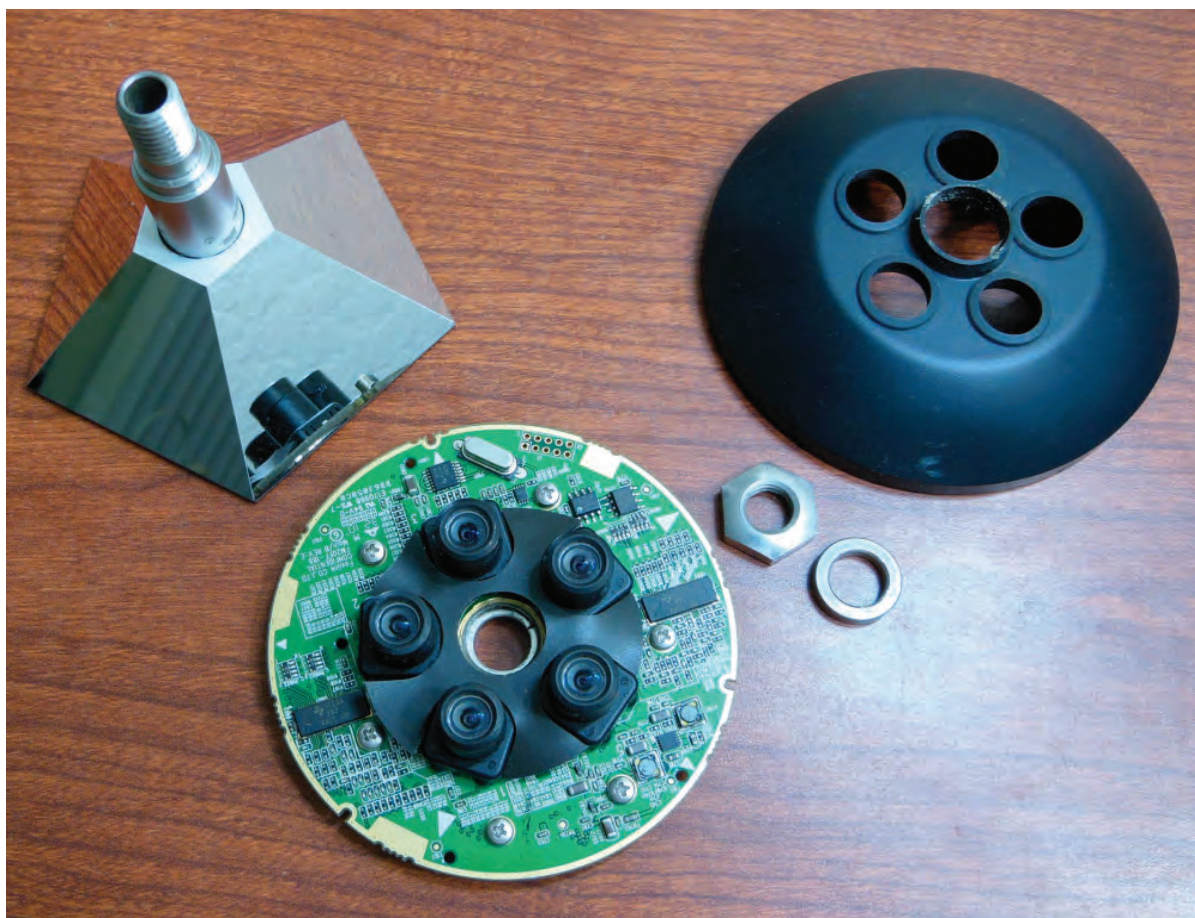
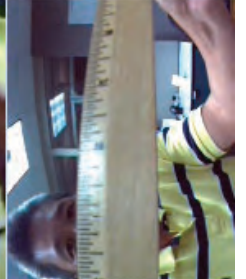
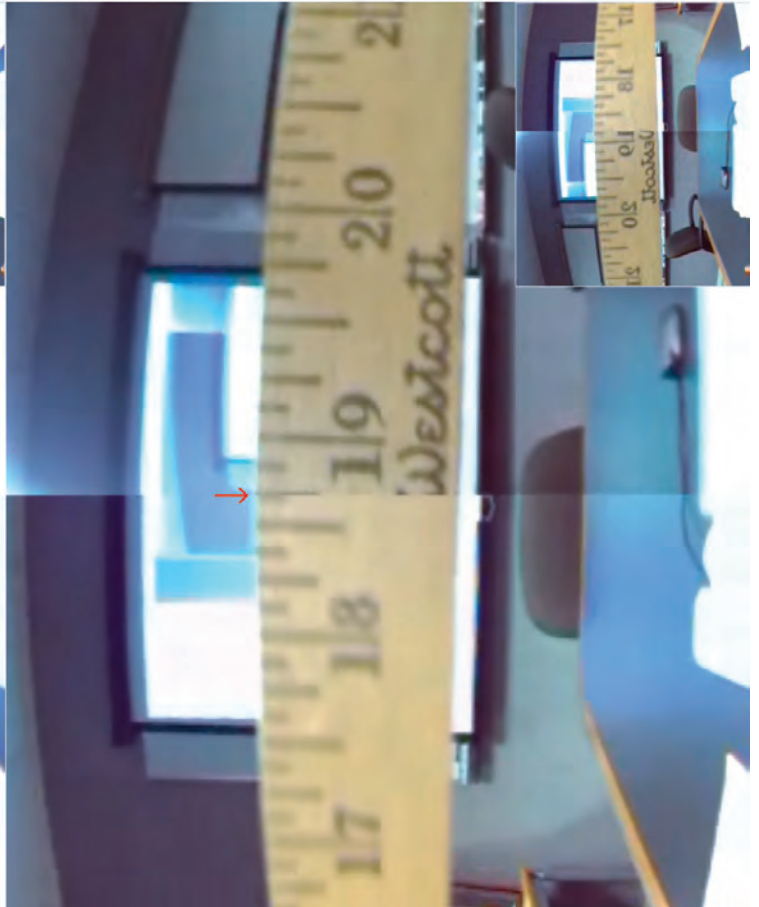


EXHIBIT D:
RoundTable Composite
Images of a Yardstick
Positioned Across a Mirror
Edge at Different Distances



September 17, 2008



April 15, 2009

EXHIBIT E:
Photograph of a FullView
Prototype Used to
Webcast a Performance
by David Bowie in 1999



CERTIFICATE OF SERVICE

I, Bruce Wecker, declare that I am over the age of eighteen (18) and not a party to the entitled action. I am of counsel at the law firm of HAUSFELD LLP, and my office is located at 600 Montgomery Street, Suite 3200, San Francisco, California 94111.

On November 27, 2019 I caused to be filed the following:

AMENDED COMPLAINT

with the Clerk of the Court using the Official Court Electronic Document Filing System which served copies on all interested Parties registered for electronic filing.

I also certify that I caused true and correct Chambers Copies of the foregoing document to be delivered to Judge Edward M. Chen pursuant to Civil L.R. 3-12(b) by noon of the following Court day.

I declare under penalty of perjury that the foregoing is true and correct.

DATED: November 27, 2019

/s/ Bruce J. Wecker

Bruce J. Wecker